THE ENGINEERING CASE STUDY AS A BASIS FOR THE MASTER OF SCIENCE THESIS

The Teradyne, Inc. Case Study: A Kinematic Interface for Semiconductor Test Equipment

by

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Submitted to the Department of Mechanical Engineering
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ABSTRACT

A case-study-based Master of Science in Engineering program is proposed. The proposed program would create a mechanism for the generation and maintenance of case studies which address the trade-offs between business and technology (“Engineering Case Studies”). An example of the Engineering Case method is presented in the form of an Engineering Case Study completed at Teradyne, Inc., a semiconductor test equipment manufacturer. Advantages of the proposed Master’s program to the student and to industry are discussed, as are potential uses of the resultant Engineering Case Study in the classroom and in industry.

Thesis Supervisor: Timothy G. Gutowski
Title: Leaders for Manufacturing Professor of Mechanical Engineering
Director, Laboratory for Manufacturing and Productivity

Dedication

This thesis is dedicated to my parents (especially my father) without whose love and support none of this would have been possible, to Shouka, whose love, patience, and understanding kept me motivated, and to my brother, Amir.

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Many thanks to: my adviser, Professor Timothy G. Gutowski, whose ideas were the foundation for this thesis and who has been very supportive of my pursuit of a non-traditional thesis path; Alexander V. d'Arbeloff, President and C.E.O. of Teradyne, Inc., for his invaluable guidance in preparing the Teradyne Case Study; and Michael A. Chiu, who taught me much about product design and improved my mechanical engineering skills.

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Introduction

Chapter 1

1.1 Background and Motivation

Traditional Master of Science programs require most students to carry out their graduate work in laboratories located in educational institutions. Often, the graduate student is isolated from the real world. This isolation can leave the student with the impression that he or she can equate real-world engineering with laboratory experiments conducted in the vacuum-like educational setting, where objectives, theory, results, and conclusions often follow in a logical order. Often, in the real-world the process is not as orderly.

This thesis proposes a case-study-based Master's program in Engineering which would give the student real-world engineering experience. Specifically, the proposed program would create a mechanism for the generation and maintenance of case studies which address the trade-offs between business and technology (the proposed "Engineering Case Study"). Master's students will work closely with industrial sponsors to develop the Engineering Case Studies, which will help the students to integrate their industrial experience with their Management and Engineering curricula . The resultant Engineering Case Study will be the basis for a graduate thesis, thereby creating a new model for graduate studies at institutions across the nation. In addition, the Engineering Case Studies will have a wide variety of educational uses in both classrooms and industry.

1.2 Outline

The remainder of this thesis is divided into five chapters. Chapter 2 outlines the traditional case method and proposes a new model: the Engineering Case Method. Unlike the traditional business case study, the Engineering Case Study focuses on the trade-offs and interactions between business and technical issues. This allows the reader to explore a particular industry in depth by emphasizing the technical aspects of a project, thereby addressing the educational needs of engineering students more comprehensively.

Chapter 3 examines the process of creating an Engineering Case Study. First, it outlines the author's process for creating an Engineering Case Study regarding a new product developed at Teradyne, Inc., a manufacturer of semiconductor test equipment. Second, Chapter 3 suggests improvements for the process of creating an Engineering Case Study. The Teradyne Engineering Case Study is presented in Chapter 4.

Chapter 5 examines alternative use of the Engineering Case Study. An Engineering Case Study can be used as the basis for a Master's program, as a study aid in the classroom, or, in industry, as a tool for continuing education. As an illustration of the potential uses, Chapter 5 also outlines the use of the Teradyne Case Study, both in an educational setting and in industry.

Chapter 6 concludes the thesis with a summary.

The Case Method

Chapter 2

2.1 The Traditional Case Method

In business education, the case method often has been closely identified with the Harvard Business School. Traditionally, Harvard Business School cases depict a real-life business problem confronting business managers at a particular moment. A traditional business case study has been defined as follows:[1]

> " A case is a partial, historical, clinical study of a situation which has confronted a practicing administrator or managerial group. Presented in narrative form to encourage student involvement, it provides data ... essential to an analysis of a specific situation, for the framing of alternative action programs, and for their implementation, recognizing the complexity and ambiguity of the practical world."

These case studies emphasize making decisions in complex situations, often, if not always, with incomplete information. Professors have used such cases effectively in business administration curricula for many years.[2]

The case method was developed in response to the shortcomings of the traditional academic approach, which lays down a complete theoretical basis from which all decisions can be made. This method of teaching can isolate the student from the intricacies of real-life situations in which they must learn to apply knowledge to solve complex problems which are not defined in a clear manner. Instead, the case method successfully provides the student with a sense of reality by depicting a situation characterized by (i) an absence of the information necessary to make decisions, (ii) conflict of objectives, and (iii) the trade-offs between needs and resources. The case method can be used to achieve many educational objectives:[3]

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[1] Barnes, Christensen and Hansen, Teaching and the Case Method, Harvard Business School Press, Boston, MA at Page 44.
[2] Id.
[3] J. S. Bloom, The Process of Learning, Cambridge, MA, Harvard University Press, 1965.

• **Evaluation**: the students form criteria, make judgments, detect fallacies, evaluate, and make a decision.
• **Analysis**: the students identify components, how they are related and arranged; distinguishing facts from fiction.
• **Application**: the students apply understandings to solve new problems in new situations when no directions or methods of solution are specified.
• **Comprehension**: the students change the information to a more meaningful form, paraphrase, interpret, infer, imply, and extrapolate when told to do so.
• **Knowledge**: the students state terms, specific facts, definitions, and categories.

The case method, however, can have various shortcomings. Although case studies are meant to depict real-life situations, they rarely do, since the case editing process eliminates certain facts by necessity. Other factors, such as class time limitations, coupled with the fact that students do not have the responsibility to implement their final decisions, can take away from the realism of case studies.[4]

2.2 The Engineering Case Method

2.2.1 Defining the Engineering Case Study

The engineer who is focused on solving problems which are purely technical in nature can learn a great deal from the traditional case study. For example, the engineer can learn about business issues and trade-offs which impact the technological development of a product. This is useful because an engineer undoubtedly will face situations in which he or she will have to make compromises in a technological solution in order to meet business goals set by management.

The traditional case method, however, though illustrative of useful business principles, does not address fully the educational needs of an engineering student. In general, business cases do not give an in depth description of the technology at hand. For example, a case might describe a particular technology very briefly as "innovative and revolutionary," while focusing primarily on management's decisions impacting the market success or failure of the new product. As a result, in reading the case, the engineering

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[4] E. R. Corey, The Use of Cases in Management Education", Intercollegiate Case Clearing House, Boston, MA, Ref. no 9-376-240.

student will learn little about the impact of technology and of engineering knowledge in making business decisions.

A case study can be more educational to engineers if it allows them to individually assess the actual technology, and then subsequently reflect on management's decisions. The proposed Engineering Case Study focuses on the trade-offs and interactions between business and technical issues in the development of new products and allows the reader to explore a particular industry in depth by emphasizing technical content. In many real-life situations, knowledge of the technical details might play an important role in making the final business decisions, while in other cases, the technical details play a secondary role in determining the final outcome. By confronting the student with business and technical trade-offs, the Engineering Case Study allows the engineer to better understand the relevance of his or her work in the context of real-life business situations.

For instance, it is important that engineers understand that often it is not a superior design which determines a product's market success but, instead, a crucial business decision. Financial, political, and marketing issues may sway management, industry, or the marketplace in favor of a product, though it is technologically inferior to other proposed designs. A classic example is the worldwide acceptance of JVC's VHS standard over Sony's Betamax standard for videocassette recorders ("VCRs"), despite Betamax's superior technological advantages. Sony's marketing strategy and restrictive licensing practices caused consumers to abandon the Betamax ("Beta") system.[5]

The battle between VHS and Beta is outlined in the Harvard Business School's case study titled "The World VCR Industry." The case looks at the evolution of VCR technology, the competition between VHS and Beta, and the emerging threats to Japanese dominance of the VCR industry.

In situations where business decisions, and not the technology, influenced the failure or success of a particular product, the traditional business case study can be an effective means of conveying the impact which business decisions can have on the success of the product. In such situations, the traditional business case study would be transformed into an Engineering Case Study by the addition of technical information which

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[5] Yoichi Yokomizo, VCR Industry and Sony, MIT Master of Science in Management, 1986.

would allow engineering students to identify more closely with the situation. For example, an Engineering Case Study might further explore the technical aspects of the Beta system's product design, as well as Sony's decision to aim for high resolution picture quality and a smaller package size at the expense of lower recording capacity.

In other situations, the technical details and technological knowledge, or lack thereof, can play an important role in management's final decision. Results can be disastrous if technical issues are overlooked in favor of business issues. An example is the decline of the American steel industry from 1975 to 1985:

> "In the postwar decades the domestic integrated producers lost their technological lead. They failed to adopt quickly the newest technologies, such as the basic oxygen furnace, continuous casting, and computer controls, as these became available in other parts of the world."[6]

Engineering Case Studies can convey effectively these important lessons to engineering students who are learning about management issues. For example, a student might learn about the need to maintain a technological lead from the Teradyne Case Study, which is presented in Chapter 4. Teradyne's success in the semiconductor industry is reliant upon top management's understanding of the technological challenges facing the industry and on their ability to implement state-of-the-art technological solutions to alleviate problems. Teradyne can launch a successful product only if the engineers and the managers fully understand the trade-offs between the technical and business issues.

2.2.2 Problems to Surmount in Using Engineering Case Studies

Departures from the traditional case structure can make the preparation and use of the Engineering Case Study very challenging. Engineering Case Studies differ from traditional business case studies in that they provide the reader with more detail regarding the technical aspects of a project. The objective of the inclusion of technical details is to demonstrate their relevance in making business decisions. The technical section should not be included to overemphasize the importance of the technical details, but rather to improve the engineering student's grasp of the technical import of the situation at hand. One way to

[6] Dertouzos, Lester, and Solow, Made in America: Regaining the Productive Edge, The MIT Press, Cambridge, MA at page 14.

avoid overemphasizing technical issues is by presenting some of the information orally. Furthermore, an instructor may supplement the technical content of a case study with short lectures. Alternatively, technical information can be provided by inviting visitors to the relevant class. A typical visitor might be an engineer from the organization about which the case was written. It is also conceivable to invite visitors who are affiliated with the same industry.

The higher level of technical detail presented in the Engineering Case Study might require the reader to possess a certain amount of technical expertise. However, this requirement should not be viewed as a disadvantage of the Engineering Case method. A certain level of background knowledge might be required even when traditional business case studies are used.[7] Furthermore, any engineer or manager who hopes to run a successful and profitable business based on technical excellence must be aware of the technological and business issues in his or her industry. The Engineering Case Study fulfills the needs of managers and engineers quite adequately by exploring the trade-offs between technical and business issues more rigorously than traditional business case studies.

An additional perceived drawback of Engineering Case Studies is that they might depict situations in which a definitive outcome has not yet been reached (See Chapter 3). One might argue that students could not learn from a case in which the real-life outcome of the situation has not been reached. However, this apparent shortcoming can be overcome by inviting guest speakers to address the students once they have completed their analyses of the case study. In this way, although the real-life outcome of the issue addressed in the case is not yet known, the students will benefit from the opinions and feedback of experts in the particular industry. For example, an Engineering Case Study could be written to outline a design problem which the company has not yet addressed. Students could be asked to analyze the situation and take into account business and technical trade-offs, before presenting their final solutions of the design problem. The students would learn to creatively identify components of an issue, to distinguish facts from fiction, and to apply their engineering education to solve new problems, in situations in which no methods of solution are specified. Moreover, as part of the exercise, the students would get the added benefit of having their proposed solutions evaluated by experts from industry. If students

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[7] I. Uterman, A Note on Case Methodology Teaching, Intercollegiate Case Clearing House, Boston, MA, Ref. no. 9-377-633, pp. 16 to 19.

were interested, they always could acquire the epilogue to the Engineering Case Study, which usually is written once the final outcome of the pertinent design problem is known.

The Process of Creating an Engineering Case Study

Chapter 3

The proposed case-study-based Master's program requires the graduate student to write a case study in lieu of a Master's thesis. This program requires close collaboration between the educational institution and an industrial sponsor, since the successful completion of an Engineering Case Study is achievable only if the graduate student is directly involved in an ongoing project at the industrial sponsor's facilities.

Section 3.1 outlines one student's process for creating an Engineering Case Study regarding a new product developed at Teradyne, Inc., a world leader in the semiconductor test equipment industry. Section 3.2 suggests improvements to the process of creating an Engineering Case Study.

3.1 An Example of the Process: The Teradyne, Inc. Case Study

Professor Timothy G. Gutowski, the director of the Laboratory for Manufacturing and Productivity of the Massachusetts Institute of Technology ("MIT"), and Mr. Alexander V. d'Arbeloff, president and C.E.O. of Teradyne, Inc., had devised a course to be taught by Mr. d'Arbeloff under MIT's Department of Mechanical Engineering's Manufacturing curriculum. The title of the course was "Management for Engineers." The 1994/95 MIT course catalog describes the course as follows:

> "Provides an overview of management issues for graduate engineers. Topic is approached in terms of career options as engineering practitioner, manager, and entrepreneur. Specific topics include semantics, finance, TQM, starting a company, and people management. Through selected readings from texts and cases, focuses on the development of individual skills and management tools."

The course had been taught successfully for one semester. However, Professor Gutowski had recognized the need to use case studies which would be more engaging to engineers at MIT. Together with Mr. d'Arbeloff, Professor Gutowski had decided to recruit a graduate student to write an Engineering Case Study for the class. The process was initiated in the Fall Semester of 1994.

The project was awarded to Ali Alagheband (hereinafter referred to as the "Graduate Student"), a first-year graduate student in Mechanical Engineering at MIT. The Graduate Student's task was to complete an Engineering Case Study pertinent to Teradyne (the "Teradyne Case Study") by the following semester. The case would emphasize a new technology being developed at Teradyne and would explore the interaction of technical and business issues related to the new technology.

Numerous texts have been written about how one should prepare and write a case study. Indeed, many aspects of writing traditional case studies do apply to writing Engineering Case Studies. However, the traditional approach does not suffice when writing an Engineering Case Study--the engineering casewriter has additional responsibilities which must be combined with the traditional approach. The following list enumerates the steps the Graduate Student completed while writing the Teradyne Case Study:

3.1.1 Tour of Facility. The Graduate Student took a complete tour of the Teradyne facilities located in Boston, given by the President of the company. During the tour, the president described problems with the relevant technology and gave an overview of how Teradyne intended to solve those problems.

- This first tour gives the casewriter an overview of the particular industry. The casewriter must be alert and inquisitive during this visit and learn as much as possible about the business and the technology. After this visit, the casewriter should have a rough idea about the project which will be discussed in the Engineering Case Study.

3.1.2 Meeting with Engineering Group. The Graduate Student met with the head of the mechanical engineering group at Teradyne and asked more questions about the industry and specific problems encountered using current technologies. The project undertaken by Teradyne to solve those problems were discussed and the Graduate Student was introduced to the mechanical engineer in charge of the project . The Graduate Student made appointments for interviews with the engineers and managers involved in the project.

• These interviews can provide the casewriter with a story line and insights unobtainable any other way. It is of utmost importance that the casewriter be fully prepared for the interviews. In collecting case content, the casewriter should be aware of the following:

• When soliciting information from any source it must be made clear that the information will not be published without the prior consent of the individual. In this way, the casewriter can be assured that the interviewee will speak freely of his/her involvement in the project.

• The casewriter must establish some degree of rapport with the interviewee. The objective is to get the interviewee interested in telling his/her story.

• Once the interviewee has told the story in his/her own words, the casewriter should follow up by asking some questions. By reference to issues the interviewee has mentioned casually, or by asking for clarification of some contents, the casewriter may be able to develop more controversial aspects of the story. Typical questions to ask are:

a. Were any other solutions to the problem considered? Why was the current one chosen? What were the trade-offs?

b. Who made the final decisions?

c. Do you see any difficulties in completing the project?

• The names and title of all individuals involved should be recorded. The case writer should retain all the sketches drawn by the interviewee while explaining specific issues. These sketches can be used for clarity in the case.

• In the course of the interviews, the engineer casewriter must obtain any materials pertinent to the problem at hand, including photographs, engineering drawings, sketches, critical memos, e-mail messages, schedules, sales literature, etc. This material is crucial to a better understanding of the company, the industry, and the project.

• The use of a tape recorder is strongly recommended. However, the casewriter should ensure that the interviewee is not intimidated by the presence of a tape recorder. A tape recorder can simplify the interview process, however the casewriter must remain an active listener by prompting the speaker to give detail and by asking for expansion when more detail is needed.

3.1.3 First Draft. The Graduate Student wrote a first draft of the Engineering Case Study using the material obtained during interviews and visits to the company.

- The first draft should serve as a mechanism to sort out information. The process starts by determining the pedagogical purpose of the case study and preparing an outline for the case. The case writer should try to list key ideas and tell the whole story in the first draft.

3.1.4 Meeting with Professor and Second Draft. The Graduate Student arranged several meetings with the profesor of the Management for Engineers class to identify the manner in which the Teradyne Case Study would be used in the class. A second draft of the Case was completed at this stage.

- The Engineering Case Study starts to take form at the second draft stage, as the business and technical issues, technologies, and trade-offs are highlighted. With the help of the faculty member, it only is necessary to determine which single purpose for which the case will be used. However, a well-written case study can be used for many purposes other than the one intended by the casewriter. In order to increase the effectiveness of the case, the writer should adhere to the following guidelines:

a. The teaching objective of the case should be clear.

b. State the problem clearly in the first two paragraphs. The case should catch the reader's interest.

c. The protagonist should be clearly identified.

d. The casewriter must determine the best means to document the facts needed by the protagonist to reach a decision. The casewriter must give pertinent background information and elaborate on issues involved in the problem. Typical background information include descriptions of the company, the product, the market, and the competition. The casewriter must remember that some readers might not be familiar with the field and its processes.

• An Engineering Case Study should contain an extensive technical section which introduces the reader to a particular technology. Special care must be taken to ensure cohesiveness between the technical and business sections of the case study.

• Clearly define the context of the problem.

• Ensure that the students can fully analyze the issue. The casewriter should include all sub-problems if deemed necessary. The reader's intelligence must be respected.

3.1.5 Completion of Second Draft. The second draft was completed through a second round of interviews and a more extensive literature search. However, the project at Teradyne had started quite recently and many details were still being sorted out. An alpha prototype of the proposed technology was still incomplete. At this point, it became apparent that the ongoing nature of the project at Teradyne and the importance of the technical section of the Engineering Case Study would necessitate a departure from the traditional approach to case writing. In writing a traditional business case study, the casewriter uses a set of information which is not changing in time since the real outcome of the case is already known. The Graduate Student felt that a comprehensive Engineering Case Study could not be written since the project at Teradyne had not evolved far enough--the business and technical details still were changing rapidly on a daily basis.

3.1.6 Part-time Work at the Company. Three months remained before the Teradyne Case would be presented in the Management for Engineer's class. At this stage, the case was set aside for a short period of time as the Graduate Student began part-time work at Teradyne. Initially, the work involved the completion of a proof-of -concept prototype of the proposed technology. This work allowed the Graduate Student to be directly involved in the project and to interact with the Teradyne engineers and managers on a personal basis.

• Before proceeding to complete a final draft of the case, it is highly recommended to set the case study aside for a short period of time. Preparation of a case requires commitment which makes it difficult to view the case objectively or discard any part of it. A dormant period increases objectivity and allows a fresh viewpoint.

Meanwhile, the casewriter can concentrate on performing those engineering tasks which will contribute to the completion of the project.

3.1.7 Final Draft. One month remained before the Case would have to be completed. At this time, an alpha prototype of the proposed technology was completed and the challenges in successfully marketing the new product were better understood by the Product Integration Managers. As a result of working at Teradyne, the Graduate Student had developed a better understanding of the technology and the relevant business issues, and a clearer sense of where the project might be headed in the next few months. In addition, the Graduate Student had the unique opportunity to attend the annual International Test Conference (ITC) in Washington D.C. This was an ideal opportunity to meet other industry experts and learn more about Teradyne's competitors and the industry in general. These developments served as an invaluable resource in completing the Engineering Case Study. A final draft of the case was written by the Graduate Student, and edited by a Teradyne engineer and the professor of the class.

- Working at an industrial sponsor's facility opens up a world of invaluable resources to the casewriter. For example, a casewriter might have the opportunity to visit customer sites and attend annual conferences relevant to the specific industry. In addition, the casewriter has the opportunity to get directly involved with the product development team. The engineer can master the technical and business issues by being directly involved in the development of state of the art technologies at leading industrial corporations. This knowledge enhances the effectiveness of the Engineering Case Study.

3.1.8 Presentation of Case Study in Class. The Teradyne Case Study was presented in the Management for Engineers class at MIT. The students were asked to prepare and present a sales plan for the new product being developed at Teradyne. As part of their preparation process, they had the opportunity to meet critical members of the Teradyne product development team one week prior to the final presentations.

- Traditionally, case studies are presented to a class one to two weeks prior to the discussion session scheduled by the professor. The student's task is to read the case and completely review any additional materials handed out and analyze the case as instructed by the professor. This approach can be used when presenting

Engineering Case Studies. However, Engineering Case Studies might describe complex technologies or products that have not yet been completed or brought onto the marketplace. In these situations, presentation of the case study to the class might require the attendance of some key figures responsible for the success of the project discussed in the case. Informational sessions can be scheduled to allow professors and students to personally interact with engineers and managers responsible for the completion of the project. This is an opportunity to better understand the technologies, the business challenges, and any further developments since the time when the case was written.

3.1.9 Further Edit. The final draft of the Case was further edited by a professional case writer at Harvard Business School. This further improved the style and format of the Engineering Case Study.

• Along with the guidelines listed in Item 4, above, the casewriter also should be aware of the following format guidelines:[8]

a. Quotes should be documented as stated.

b. The casewriter should use subheadings for further clarification. These may correspond to an outline's headings.

c. The length of the various sections should be proportionate to their importance to the case. The casewriter must critically evaluate the importance of a particular section to the problem presented by the case.

d. When using people's names, the casewriter must describe their role in the case. If their position is irrelevant to the decision-making, quotes or actions should remain anonymous.

d. The case narrative should flow similar to a story relating cause and effect.

e. The casewriter must be wary of expressing his/her opinions or interpretations in the case. Text which is not included in quotes is considered to be factual. Any issue that is debatable should be attributed to a person.

f. All tables and graphics should be comprehensible. All tables and graphics should be accompanied by titles and notes describing the data which they present.

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[8] Provided by Karen Monsler, Research Assistant at the Harvard Business School.

3.1.10 Full-time Employment. The Graduate Student began to work at Teradyne as a full-time employee the following summer and through the end of January, 1996.

- Industrial sponsors benefit substantially by participating in the proposed program. MIT engineers and their work can be invaluable in the development of state of the art technologies and the completion of projects in progress. Moreover, the sponsors have the unique opportunity to recruit these engineers upon the completion of their Master's program, which serves as a "training" period.

3.2 Improving the Process

There are a number of ways to improve the process of creating an Engineering Case Study. The following is an abbreviated list of possible improvements.

3.2.1 Instituting Faculty Member Involvement

In order to initiate a case-study-based Master's program, it is educational institution's task to identify potential industrial sponsors interested in participating in the program. The Teradyne Program was initiated by the President of Teradyne, who was teaching a graduate course at MIT. With the help of an MIT faculty member, he recruited a graduate student to write a Teradyne Case Study for the class.

The uniqueness of the Teradyne experience should not be seen as a deterrent to this proposal. In fact, the unique circumstances surrounding the Teradyne experience only served to isolate the Graduate Student from his thesis adviser's main research interests. College faculties have ties to many industrial corporations and are performing sponsored research in many laboratories across campuses nationwide. Ideally, the faculty's research interests should be tied closely to new technologies being developed by the chosen industrial sponsor. If the proposed Master's program is initiated in this way, the graduate student will benefit from the faculty adviser's experience, guidance, and supervision in conducting the research pertinent to the case study.

3.2.2 Establishing Funding

Involvement of an MIT faculty member could resolve another important issue: funding. A major hurdle to the success of the proposed Master's program is the issue of funding the student involved. The Graduate Student described above was only funded for two semesters by MIT and was considered to be a Teaching Assistant during that time. After those two semesters, MIT ceased funding the Graduate Student and he became a full-time employee of Teradyne, thus securing funding for the summer period. Fortunately, Teradyne also agreed to pay the Graduate Student's tuition for the following semester.

MIT's justification for stopping the funding of the Graduate Student was that any work done following the completion of the case study was beneficial to only Teradyne. Involvement of faculty member can resolve this situation since the graduate student's work would be of interest to the educational institution and the thesis adviser's research interests. It is strongly recommended that the educational institution and the industrial sponsor agree on a cost-sharing scheme before recruiting any graduate students. The agreement should cover tuition and stipend expenses for the expected period of study. If such an agreement proves impossible, only graduate students with fellowships should be considered for the project.

3.2.3 Increasing the Time-frame for Completion of the Case Study

In general, the duration of the proposed Master's program should be 1.5 to 2 years. This time-frame gives the graduate student ample time to complete the course requirements for a Master's thesis, conduct valuable research and gain practical engineering experience at the industrial sponsor's facilities, and compile enough information to write an Engineering Case Study. The Engineering Case Study should be completed towards the end of the proposed Master's program. The Teradyne Case Study was written and presented too prematurely. It was completed in a span of seven months and dealt with a project which had been initiated only three months previously. Even though a final draft of the case was completed and presented in the class for which it was drafted, it was apparent that the case could have been improved if written towards the end of the Graduate Student's Master's program.

The Teradyne Case Study could have been drafted more effectively by incorporating developments which occurred after the completion of the original version. Upon the completion of the case study, the Graduate Student continued work at Teradyne as a full-time employee for eight months. During this time, the Graduate Student had the opportunity to get more involved in the development of an innovative technology at Teradyne. More specifically, this was an opportunity to closely observe the product development process at Teradyne and assist in the evolution and verification of the proposed technology. In addition, the Graduate Student worked with Product Integration Managers in charge of the new product to assemble a plan improving the likelihood of the product's market success. The project had come a long way since the Teradyne case was presented in class nine months previously. The Graduate Student had become more involved and was now an integral part of the product development team at Teradyne. The Teradyne Case Study would have been more complete if it had been written at this stage of the student's Master's program. For example, the case could have included more information about Teradyne's competition in the mechanical interfacing business, including a more detailed description of the competitions' products. The case also could have included opinions of several key figures responsible for the launch of the new product into the marketplace. With this additional information the casewriter could formulate multiple marketing strategies for the students to analyze as a class assignment.

A Sample Engineering Case Study

Chapter 4

The version of the Teradyne Case Study presented in Chapter 4 is a slightly modified version of the original case presented in the Management for Engineers class. This version incorporates the work done by the Graduate Student at Teradyne and has been edited as per the suggestions of Karen Monsler, a professional casewriter at the Harvard Business School.

Laboratory for Manufacturing and Productivity
Massachusetts Institute of Technology

CASE STUDY

Teradyne:
A Kinematic Interface for Semiconductor Test Equipment

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Ali Alagheband

June 1995
Laboratory for Manufacturing and Productivity

Teradyne:
A Kinematic Interface for Semiconductor Test Equipment

Alex d'Arbeloff, President of Teradyne, Inc. (Teradyne) and Alex Slocum, a professor of Mechanical Engineering at the Massachusetts Institute of Technology (MIT) were at the Teradyne building in Boston. "Alex was showing me a semiconductor tester and explaining that he was having a hard time positioning it in a repeatable and reliable manner," recalled Professor Slocum. The problem involved the inability to repeatedly and reliably align two complex pieces of machinery to within 0.001" in the x-y plane and 0.005" in the z-direction. Professor Slocum had an immediate solution: "If you have a problem repeating, use a kinematic coupling." That night marked the beginning of the joint MIT-Teradyne project focusing on the design and development of a mechanical interface for the next generation of semiconductor automatic test equipment.

The introduction of increasingly complex semiconductor devices has dictated the need for more reliable and precise mechanical docking schemes. Teradyne's cooperation with the MIT Precision Engineering Research Group resulted in a joint effort to design a mechanical docking system which would accommodate the newer, bigger, and heavier Teradyne testers and allow more repeatable interfacing with automatic handling devices. The new docking system also would give Teradyne the opportunity to create a new business by assuming the responsibility of manufacturing the mechanical interface components of test equipment and providing semiconductor manufacturers with a technology which would increase productivity and minimize costs.

Depending on the customer needs and a careful study of the economics of the existing customer setups, Teradyne could offer the new docking technology independently and retrofit it into the existing equipment on the customer factory floors, or it could package the technology with a new system and require the customer to purchase an entire machine.

The increase in capital costs of wafer fabrication has forced semiconductor manufacturers to demand more efficient and productive testers at lower costs. Economic considerations have become essential to the selection of Automatic Test Equipment (ATE), thus manufacturers consider the *overall cost of ownership* of ATE before making any purchase commitments. Teradyne's marketing and engineering groups, led by Randy Thomae and Michael Chiu respectively, were faced with some questions. Which option, retrofitting or installing an all new system, would be more profitable to the customers? Could customers justify the initial capital loss associated with purchasing a new system, as opposed to retrofitting?

4.1 How are Semiconductor Chips Tested?

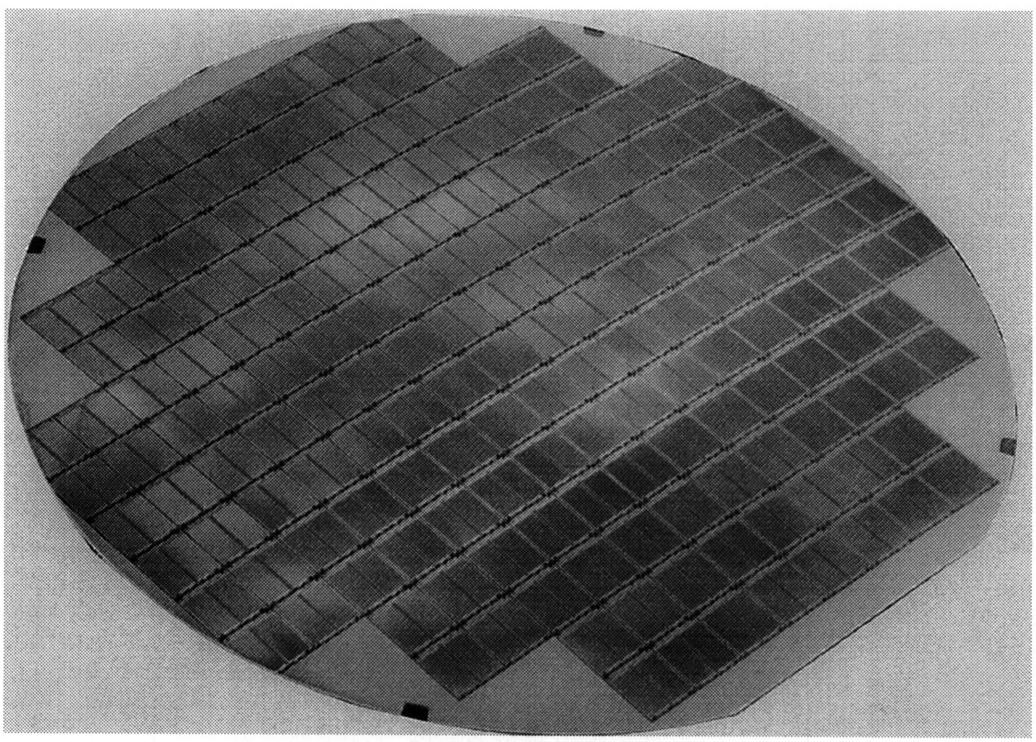


Exhibit 1: The Wafer

Semiconductor components generally are produced in large quantities and are tested at various stages of the manufacturing process. Initially, the semiconductor integrated circuits (ICs) are fabricated on large silicon wafers which are 6 to 8 inches in diameter (Exhibit 1). Therefore, a wafer consists of numerous individual ICs (the rectangular sections on the wafer in Exhibit 1).

Semiconductor manufacturers test each wafer to determine which individual ICs are defective. Generally, and as is described more fully in Section 4.1.1, a wafer is placed in a handling device which presents the wafer to a testhead attached to a mainframe computer. The testhead sends and receives signals by which the mainframe can determine which individual ICs are flawed.

After testing, the wafers are cut into individual ICs and the defective ICs are discarded. The remaining ICs are mounted into frames. The frames are then encapsulated in plastic or ceramic packages which constitute the final product--a chip. The chips are tested a final time before shipment. However, since the encapsulation process is relatively expensive, manufacturers have a significant economic incentive to test and discard faulty ICs early in the process, when they are still on the wafers (Appendix D).

IC testing is done with Automatic Test Equipment (ATE). Teradyne is the world's largest manufacturer of such equipment and provides semiconductor manufacturers with test systems for a variety of circuit types: Digital IC (Logic and Memory), analog, digital, and mixed-signal (analog and digital combined). Exhibit 2 shows a Teradyne mixed-signal A570 tester.

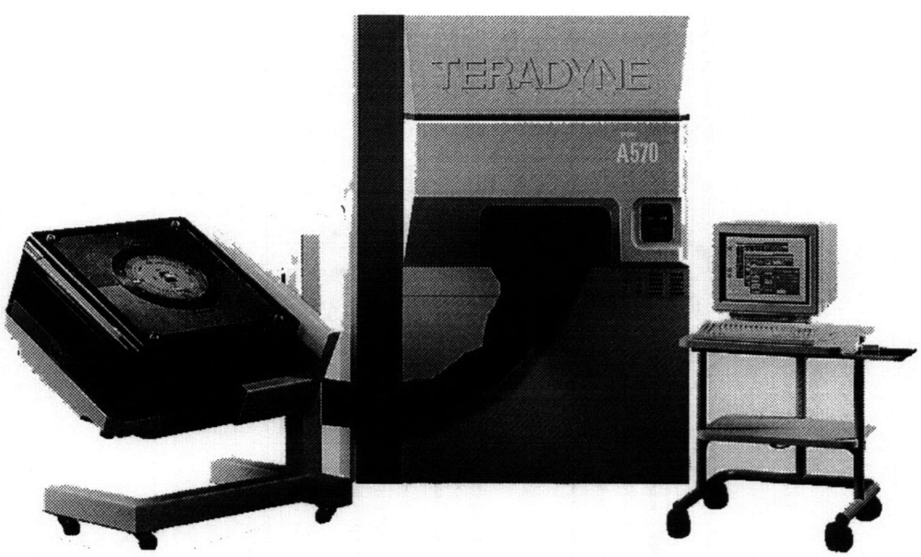
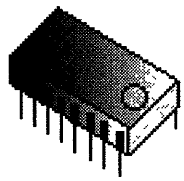
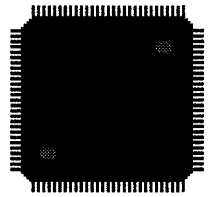


Exhibit 2: Teradyne A570 Tester

4.1.1 A Description of the Current Technology





Yesterday's **Today's**

Exhibit 3: Semiconductor ICs

Today, semiconductor integrated circuits have as many as 300 inputs and outputs (Exhibit 3). A *testhead* simulates actual operating conditions by sending and receiving hundreds of electrical signals to the semiconductor component. The testhead, which includes all of the driving and receiving circuitry, can be up to a few feet in diameter and can weigh in excess of 500 pounds. The testhead is connected via a cable bundle (up to 10 inches in diameter) to an electronic cabinet, or *main frame,* which contains data processing circuitry (Appendix A). This circuitry determines which signals should be driven and compares the received signals to expected values, thereby determining which ICs are faulty. The cable bundle is thick, carrying wires responsible for powering the testhead and transferring the signal to and from the hundreds of spring pins in contact with circuit boards inside the testhead. As semiconductor devices become more complex and contain more inputs and outputs, more wires will be necessary to conduct the testing, thereby making the cable bundle even larger. The test systems use coaxial cables for high frequency testing, shielded and twisted cable pairs for digital signal processing, and ribbon cables for basic DC signals and the various data buses.

In order to efficiently test integrated circuits, a device is needed to position each IC relative to the testhead. In the wafer stage, a *prober* is used to accurately position the IC. The ICs on the wafer can be tested separately or in parallel. Once the device is packaged, handlers are used to position the IC relative to the testhead. Probers and handlers generally are referred to as handling devices.[9] The testhead is connected (docked) to the handling device via a multilayered interface (Exhibit 4).

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[9] This case focuses on the use of ATE in the wafer stage. In recent years, the wafer test has become an increasingly important stage in IC manufacturing (Appendix D). The technical and business issues are equally relevant to the Final Package Test stage.

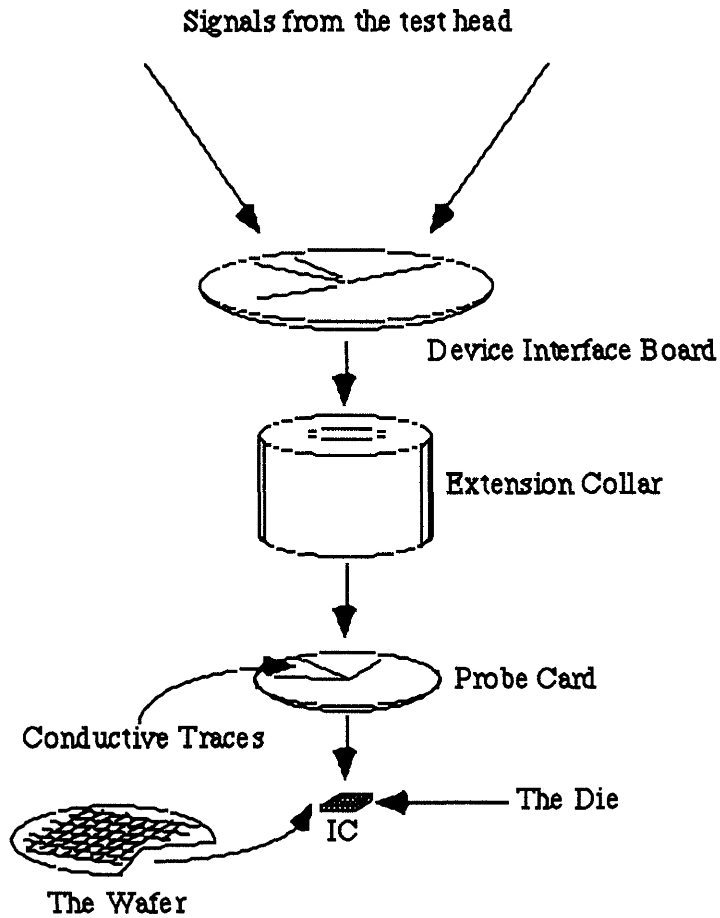
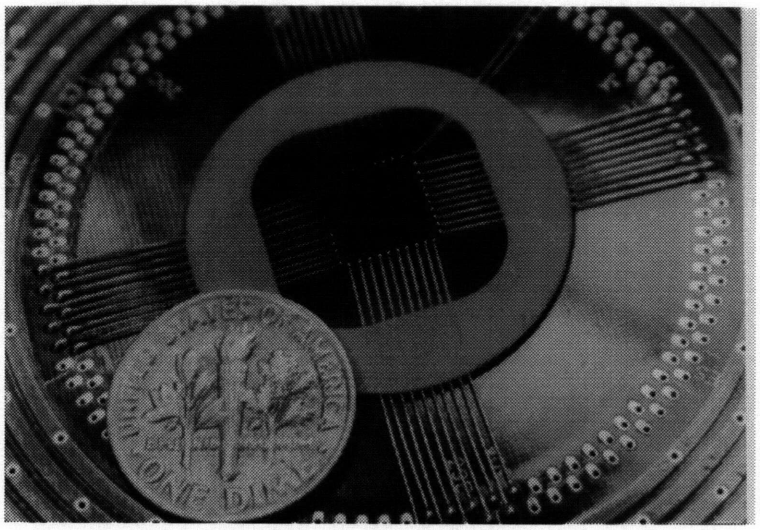


Exhibit 4: The Multilayered Interface

In general, this interface is on the prober before the testhead is docked. The primary purpose of the interface is to direct the hundreds of signals leaving the testhead and to bring them to a 0.003" x 0.003" contact area on each IC being tested, achieving the electrical contacts to within the required accuracy of 0.001". The multilayered interface transfers signals from the testhead to the *device interface board* (DIB), then to the *probe card* (through an extension collar), and, finally, to the IC (through the tungsten probe needles) (Exhibit 5). Historically, probe cards cost less than device interface boards (DIB). Manufacturers preferred to replace probe cards rather than DIBs. The multilayered interface between the testhead and handling devices provides manufacturers with the flexibility to replace the inexpensive probe cards which get worn out over time and retain the DIBs in their testers.



The Probe Needles

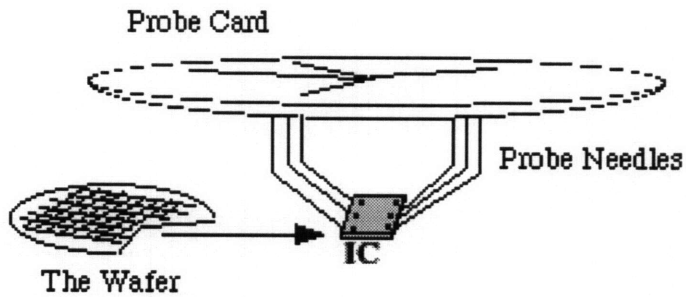


Exhibit 5: Probe Needle Alignment with Bond Pads on the IC

4.1.2 The Technical Challenges Facing the Current Technology

The testhead needs to be maneuvered and mechanically fastened (docked) to the prober in order to properly align the probe needles with the IC being tested. In order to facilitate movement, the testhead is attached to a *manipulator.* The manipulator contains counterweights or other mechanical devices to make the movement of the testhead easier (Exhibit 6). Using the manipulator, the testhead is mechanically *docked* to the prober.

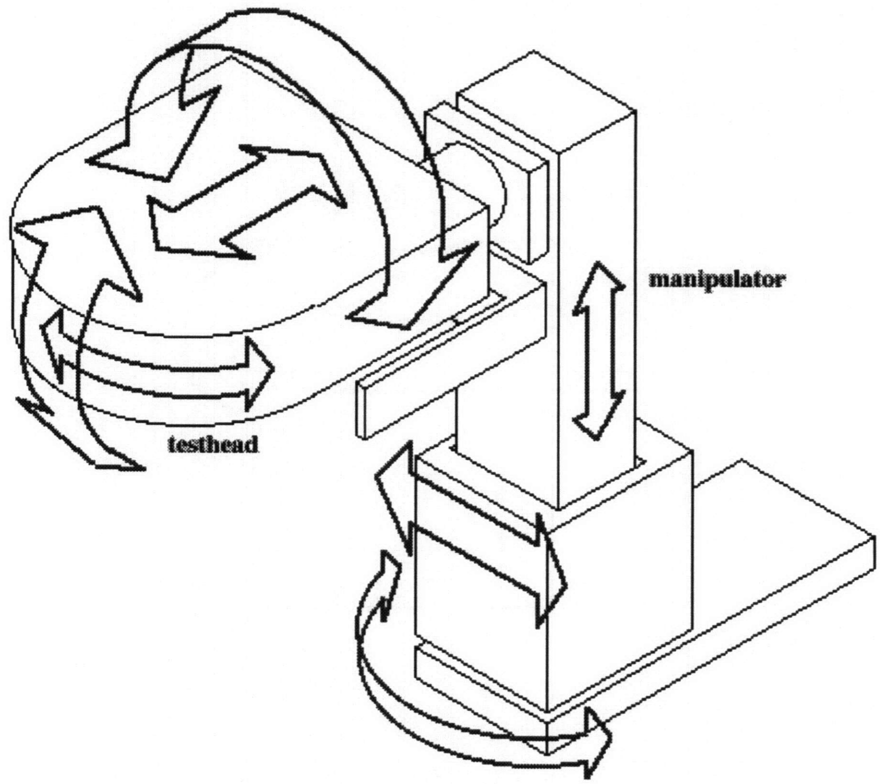


Exhibit 6: The Manipulator

The trend in the semiconductor industry has been the production of faster and more complex chips. Technical road maps show that chips will have as many as 1000 inputs and outputs by the year 2000. The trend toward an increase in the use of high pin count ICs is shown in Table 1.

IC PIN COUNT	1990 (in millions)	Projection for 1995 (in millions)
11-16	25,400	28,300
17-24	10,700	17,900
25-40	6,500	11,100
41-64	2,600	7,500
65-96	3,100	9,800
97-256	1,700	9,000
>256	300	3,900

Source: VLSI Research, Inc.

Table 1: Projection for Number of IC Packages Used

With the introduction of more complex devices and increased IC pin counts, greater accuracy must be provided by the testers in aligning the probe needles with the IC being tested. For example, one way to solve the precision alignment problem is by mounting four guiding posts on the top plate of the prober (Exhibit 7). The purpose of the guiding posts is to accurately position the testhead relative to the prober. However, since the guiding posts cannot restrain the six degrees of freedom of the testhead, the four post method of alignment does not provide any *repeatability* (i.e., once the testhead is removed, it cannot be repositioned exactly).

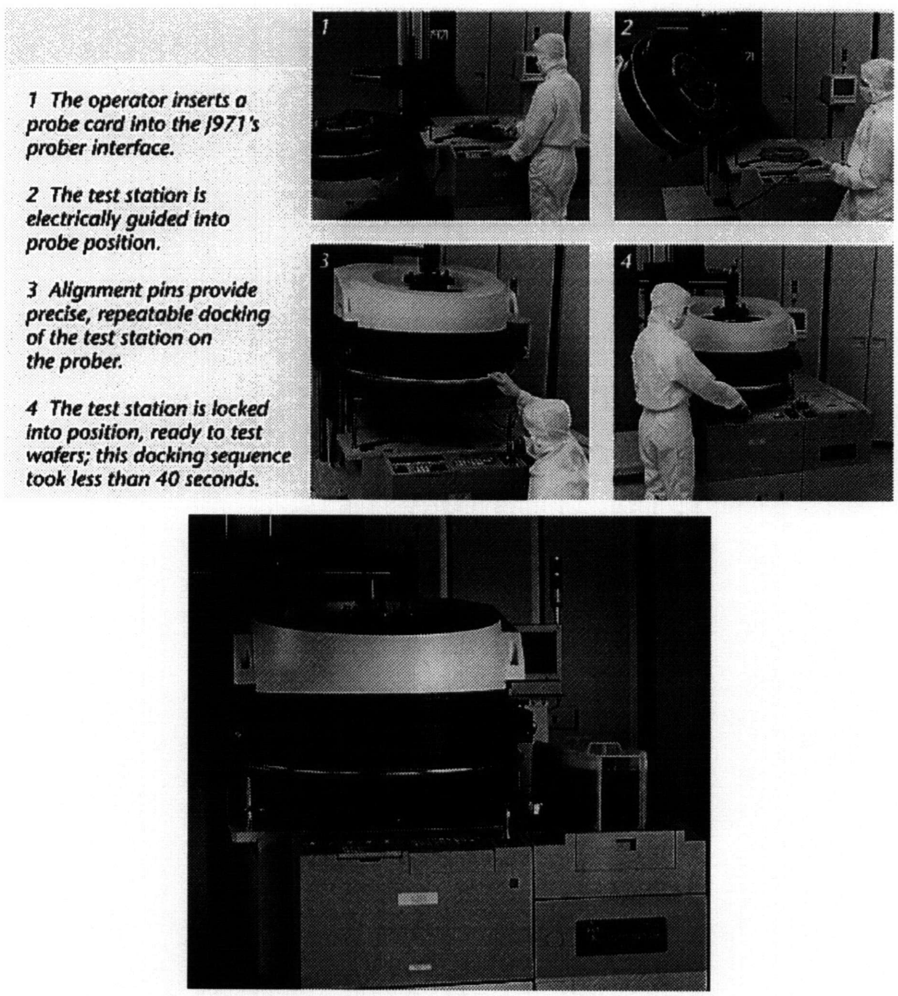


Exhibit 7: Demonstration of the Docking Sequence of a Teradyne J971 Testhead to a Prober Using a Four Post Method of Alignment

Another challenge facing the current technology is to position every probe needle in the center of the device bonds (0.003" x 0.003"). This cannot be achieved if the probe needles are not planar to the wafer. This task will become even more challenging with the introduction of the next generation Teradyne testers, which are bigger and heavier than their predecessors. The four post method does not support the weight of the testhead. This can result in probe card deflections which twist the probe needles out of a planar configuration (Appendix C). Michael Chiu, a mechanical design engineer at Teradyne, describes the problem as follows:

> "The prober, by nature, can compensate for inaccuracies in positioning. Assume we put the testhead down once and it falls in position x . Then undock the testhead and put it down again and it falls in position y. The prober can accommodate for this as long as the probe needles are not twisted out of plane. It is really not an accuracy problem, it is a repeatability problem."

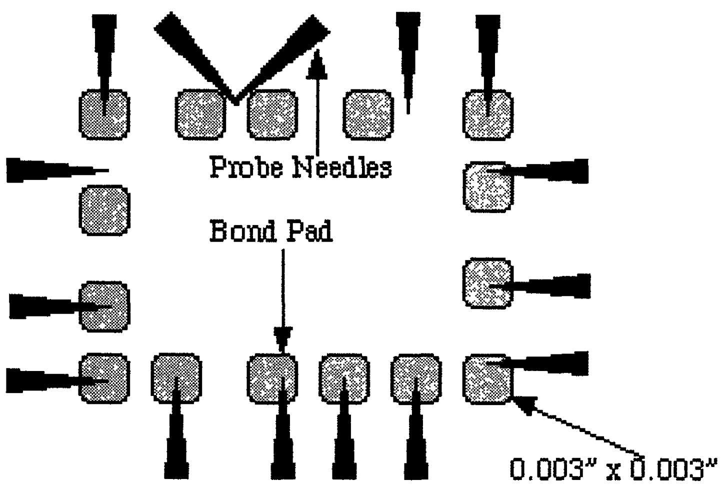


Exhibit 8: Poor Probe Needle Tip Alignment Due to Probe Card Deflections

Probe card deflections can have severe consequences. Poor probe needle alignment increases the occurrence of shorting between adjacent probes. Moreover, probe tips which protrude lower than their neighboring needle tips will create deep and damaging scrub marks, making it difficult to reliably bond wires to the pads in the packaging stage (Exhibit 9). Furthermore, normal tungsten probe needle tips require cleaning every 1000-10,000 touchdowns. This causes the tips to wear down excessively and shrink away from the acceptable radius of bond-pad contact.

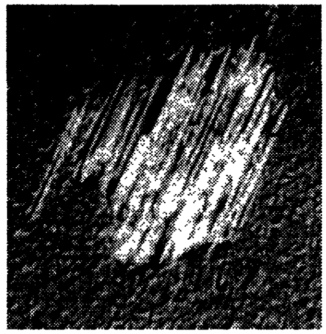


Exhibit 9: Probe Needle Scrub Mark (x2000)

A typical scrubbing force is about 3 to 5 grams per point of contact. Table 2 shows typical scrubbing pressures on IC bond pads. Combined with the mass of the testhead, these forces further complicate the task of repeatable alignment and precision. Non-planar probe tips also increase contact resistance for those probe tips that are higher than their neighbors, causing inaccurate voltage levels which may result in false flaw indications during the IC device tests.

Pin Count Per Die	Number of Die Probed in Parallel	Total Probe Pins	Scrubbing Force on the Die and Wafer at 5 grams/point
20	8	160	0.8 Kg 1.8 lbs
20	16	320	1.6 Kg 3.9 lbs
80	8	640	3.2 Kg 7.1 lbs
80	16	1280	6.4 Kg 14.1 lbs
240	8	1920	9.6 Kg 21.1 lbs

Source: VLSI Research, Inc.

Table 2: Probe Needle Force on the Wafer

The precision alignment task is further complicated by the four different models of probers available to semiconductor manufacturers. The major suppliers of wafer probers are Tokyo Electron Ltd., Electroglas Inc., and TSK. The various shapes and sizes require various docking interfaces to achieve docking. The current manipulators and mechanical interface modules are not capable of providing the required flexibility. Due to lack of compatibility, end users often change docking hardware on a given prober so as to move it from one testhead to another.

4.1.3 Solutions to the Technical Challenge

4.1.3.1 The Competitors' Solutions to the Technical Challenge

In response to problems associated with deflections of the probe card, several trends have been initiated in the ATE industry. One of the most notable is the introduction of the hinged manipulator by the Japanese (Exhibit 10). This set up results in cost savings due to the elimination of certain components, such as the conventional manipulator. However, the hinged manipulator does not provide manufacturers with any flexibility. Once installed, the testhead remains on one handling device. Moreover, repeatability cannot be achieved.

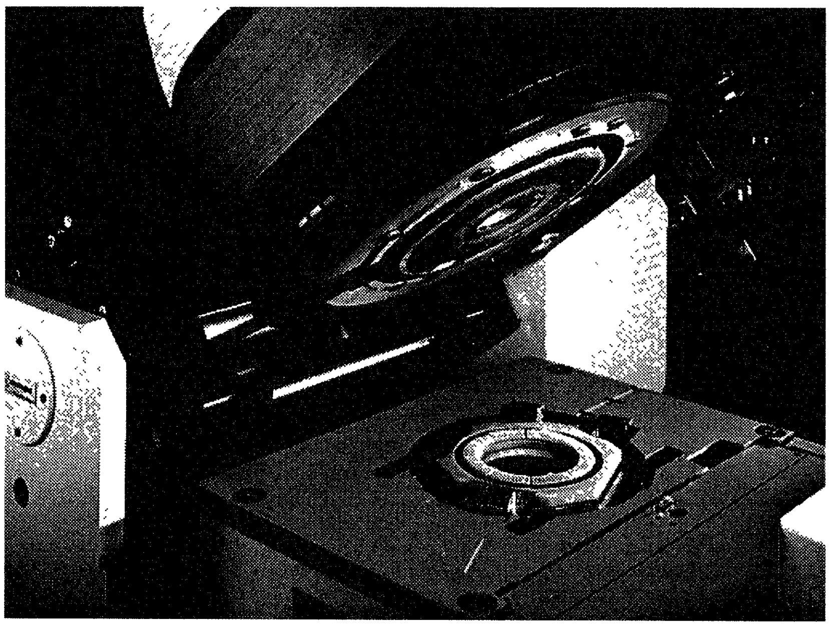


Exhibit 10: Hinged Testhead Manipulator

Other efforts have concentrated on eliminating the probe needles by using *membrane probe cards* (Exhibit 11). The membrane probe card uses spherical contact points or "bumps" to make contact with the wafer. The use of membrane probe card reduces damage to the bond pads (Exhibit 12). This technology also eliminates the need to replace needle probes periodically due to breakage or bending. However, probe cards which satisfy high precision requirements and use membrane technology can cost between $10,000 and $20,000 and, therefore, are not used widely by the industry.

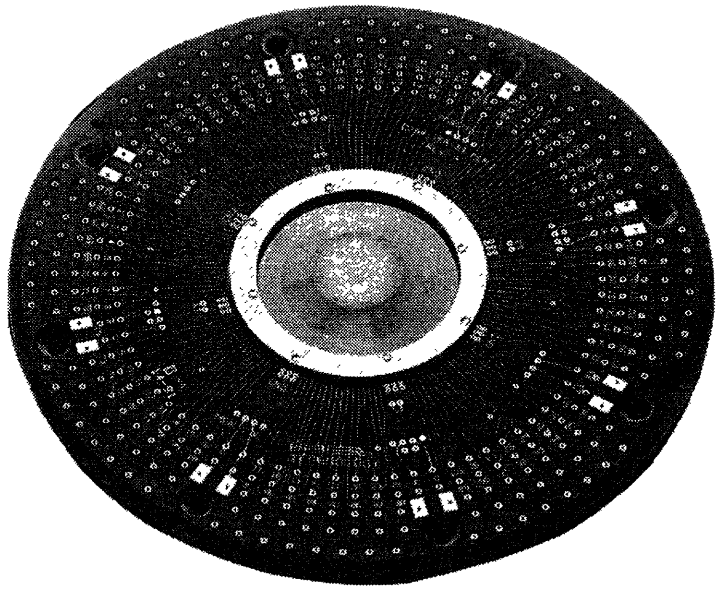


Exhibit 11: A Membrane Probe Card

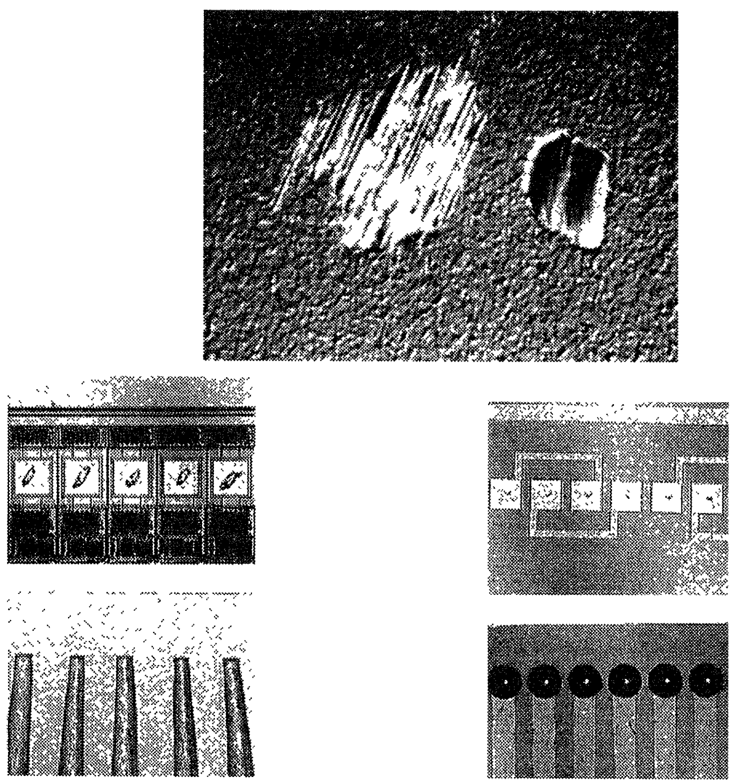


Exhibit 12: Probe Needle v. Membrane Scrub Marks

Recently, probe needles have been integrated with the device interface board in some applications. The elimination of the probe card does not resolve repeatability issues since the DIB can deflect just as readily as a probe card when subjected to the various docking forces.

4.1.3.2 Teradyne's Solution to the Technical Challenge

Professor Slocum's Precision Machine Design Group at the MIT has suggested that *kinematic coupling* be utilized as the mechanical interface between the testhead and the prober, to precisely and repeatably position the testhead relative to the prober. In order

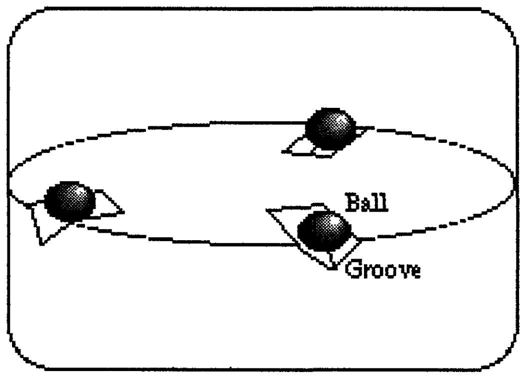


Exhibit 13: Three Ball and Groove Kinematic Coupling

to achieve kinematic coupling, the six degrees of freedom of a rigid body must be restrained by the coupling. In order to constrain motion in the six degrees of freedom, six contact points are needed, provided that no more than two of the contact points are collinear. For example, three spherical balls and V grooves constitute a kinematic coupling (Exhibit 13). Any additional contact points would create over-constraint in the system. This over-constraint has at least two effects. First, because any real solid body is not absolutely rigid, the over-constraint may cause deformation of the body resulting in positioning inaccuracies. Second, the over-constraint creates a non deterministic system where the position of one rigid body relative to another may not be repeatability maintained.

Each pair of a ball and a groove is a "kinematic contact". Each side of the groove is a "kinematic surface" and provides for a single contact point. The ball is a "kinematic mating surface" and contacts a kinematic surface at exactly one point. One way to implement kinematic coupling would be to mount the spherical balls on the underside of the testhead (Appendix E). Three grooved blocks would be attached to the top plate of the prober. This would allow semiconductor manufacturers to dock the testhead to the prober in a repeatable manner. The use of the kinematic coupling will reduce set up times and increase the flexibility of the ATE equipment.

Michael Chiu, a mechanical engineer responsible for the implementation of the kinematic coupling interface on future Teradyne test equipment uses the following analogy to describe the inner workings of a kinematic coupling,

> "A simple illustration of the difference between a kinematic and non-kinematic coupling is seen in comparing a 3-legged stool to a 4-legged chair. The stool will always rest on the three legs without rocking. However, this is not true of the chair. Unless the chair legs are exactly the proper length and the floor is perfectly flat, the chair will either rest on 3 legs and rock or it will deform so that all 4 touch. Neither rocking nor deformation is acceptable if we want to know exactly where the chair sits. The three contact points of the stool are planar-kinematic and are sufficient to position it relative to the floor, but it is still free to slide and spin. If fewer are used, the stool will fall over, and if more are used deformation is required to get them to touch."

However, the current manipulators cannot accommodate the desired kinematic coupling, because such an interface requires that the testhead be freely compliant in all directions. Current manipulators are not compliant to the requisite degree. In designing the Teradyne manipulator, Firestone air actuators were used to keep the testhead "floating" such that an operator could maneuver the testhead with less than 50 pounds of force in all directions. This also minimizes any unwanted forces on the kinematic coupling interface, which pulls the testhead and the prober together (Appendix E).

4.2 The Company

4.2.1 Company Profile

Teradyne was founded by Alex d'Arbeloff and Nick DeWolf in 1960 in downtown Boston. With its inception, the Automatic Test Systems industry was born. Teradyne's first product was an automatic diode tester. This highly reliable system was the first tester with no vacuum tubes. The whole system was the size of a bread box, while competitors' testers were six foot high racks of electronics. Teradyne's diode tester was a revolutionary concept in 1961.

Today, Teradyne's business focuses on the creative application of systems technology to practical problems in the design, manufacture, and servicing of electronics.

Teradyne's products include semiconductor, circuit board, and telecommunication test systems. The company's systems are used by component manufacturers in the design and testing of their products, by electronic equipment manufacturers for the incoming inspection of components, and for the design and testing of circuit boards and other assemblies. Manufacturers use such systems and software to increase product performance, to improve product quality, to shorten time to market, to enhance manufacturability, to conserve labor costs, and to increase production yields.

4.2.2 The Market

The company sells its products across most sectors of the electronics industry and to companies in other industries that use electronic devices in high volume. Direct sales to United States Government agencies accounts for a small percentage of net sales (2% in 1993). Sales to overseas customers accounted for 41% of net sales in 1993. Teradyne's overseas customers are located primarily in Europe, Asia Pacific, and Japan. Almost all of Teradyne's manufacturing activities are conducted in the United States. In addition, the company has two small factories in Japan and Ireland.

Currently, the leading US and Japanese companies in the semiconductor industry include 10 ATE companies, 3 prober companies, and 7 handler companies (handlers are used to position the packaged chips relative to the testhead for the "Final Package Test"). There is insufficient communication between testhead manufacturers and prober/handler companies and the coordination of interests proves to be rather challenging.

The ATE industry has been mainly concerned with electronics and electrical design. Historically, problems have not demanded the attention of first-class mechanical engineers and could be solved by electrical technicians alone. Initially, testers were mechanically simple. However, as semiconductors circuits have grown in complexity, testers have become more mechanically complex. Minor mechanical problems have gradually evolved until they impede progress and demand a solution. Alex d'Arbeloff uses a comical analogy to describe the situation:

> "If you drop a frog in a pot of hot water, it will jump back out instantly. But if you place the frog in a pot of cold water and gradually heat up the water, the frog stays put. The water will boil and the frog is doomed."

Testers have been sitting in cold water for a long time and finally the water is starting to boil.

Many of the industry's technical difficulties have probably been solved, at least in theory, by experts in other fields. MIT's Professor Alex Slocum suggests a novel approach to the industry's problems:

> "If you look at a particular industry, the chances are that everybody in that industry thinks alike. They are inbred. The business moral of the story is that to really be a big international company, you have to actively *cross-pollinate* with other disciplines and industries."

Indeed, Teradyne has achieved this by cooperating with Professor Slocum's group at MIT. Other potential alliances would involve companies in the machine tool industry and electrical technicians from the aircraft industry. By consulting with experts from other fields, Teradyne can improve the quality of its products and gain an advantage over its competitors. The joint MIT-Teradyne project has resulted in the development of concepts such as *kinematic coupling* and a radical redesign of the current manipulators. These are perhaps some of the answers to the complex problems faced by the industry.

4.2.3 Competition

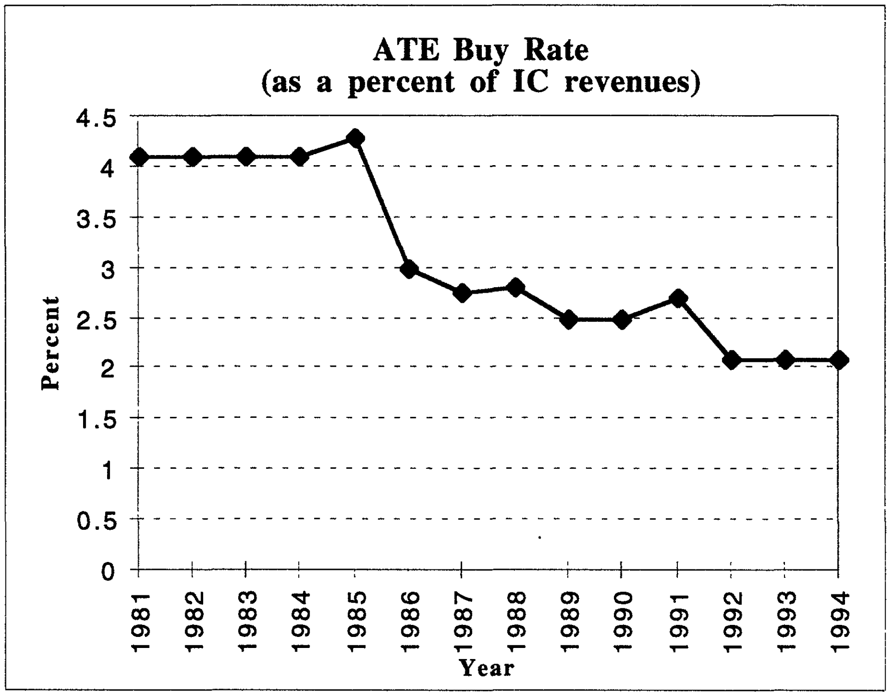
Competition is intense in each of the business areas in which Teradyne operates. Competition principally is based on technical performance, equipment and service reliability, reputation, and accessibility to the vendor, and price.

4.3 The Business Challenge

Trends show that the ATE buy rate, as a percent of semiconductor sales, has leveled off in recent years (Exhibit 14). The introduction of new and superior mechanics could give semiconductor manufacturers enough incentive to spend a larger percentage of semiconductor sales on ATE setups. Michael Chiu is optimistic about the opportunities.

> "Right now mechanical problems plague the whole industry. The fact of the matter is that people do not buy testers because the mechanics are great; they buy them because the electronics do what they want them to do. People buying these systems are electrical engineers and they are looking at the tester's speed and the number of available channels for test. Alex d'Arbeloff's theory is that if we really do this right, people will be willing to pay good money for good mechanics. People on the test floor who use these machines everyday know the importance of having good mechanics. If we can show that these poor

mechanics are costing them money and that Teradyne has an elegant solution, then they will buy it."



source: VLSI Research, Inc.

Exhibit 14: Tester Buy Rate

In general, gradual improvement is more difficult to achieve since the customer will not have a significant economic incentive to adopt the new technology. On the other hand, a revolutionary modification of the equipment will succeed only if it can change the economics dramatically. Either way, Teradyne's task is to convince semiconductor manufacturers to buy the new mechanical interface. If successful, revenues will increase and Teradyne will gain market share as customers begin to prefer and purchase Teradyne's test systems.

As a first step, the engineering team has to choose the correct strategy and make careful design compromises to assure the success of the project. Michael Chiu and his colleagues know that the kinematic coupling can provide more than just repeatability. For example, it can be configured to allow manufacturers to *automatically* planarize probe cards. This would require advanced motion control and sophisticated communication capabilities between the testhead and the prober. However, Teradyne's strategy is to complete a manual version of the docking system first. This version would provide the customers with repeatable docking only. Michael Chiu justifies the decision:

> "We have a new product to ship and have to meet the deadlines. The manual version will not be as functional as a fully automatic version, but it will perform better than what is already out there. We want to introduce this system to the market as soon as possible anyway. This will allow us to remove any bugs before implementing the more complex version."

Meanwhile, marketing product manager for the mechanical interface, Randy Thomae, has the task of successfully marketing this new interface by convincing customers of its potential economic impact. As a starting point, Michael Chiu's suggestion is to target manufacturers who have problems with their system and implement the kinematic coupling interface on their setups. "The interface has been designed to be backward compatible with existing equipment," he explains.

In order to successfully market the new product and devise a successful business plan, a careful examination of the customer needs and the economics of the customer setups is essential. In this case, the new docking system can be thought of the solution to what are primarily economic problems: minimizing costs and maximizing productivity. A successful marketing strategy requires a complete understanding of the customer's preferences, installed base, and manufacturing process requirements.

For example, because of the large variation in devices under test and short production cycles, it is often necessary that the testhead and prober be decoupled so that the probe card, DIB, or prober be changed. The testhead must be realigned with the prober quickly, repeatedly, and efficiently. Otherwise, increased setup and re-setup times can become costly to semiconductor manufacturers. The unreliability of the system can lead to increased downtime and yield loss. In order to maintain an acceptable level of productivity, manufacturers keep losses at a minimum by adding excess test capacity to the factory floor. These, and other similar issues, can be understood and investigated by observing the semiconductor manufacturing operations on the factory floor. Randy Thomae has spent several weeks on the factory floor of numerous Teradyne customers to better understand the issues at hand. This will allow him and his team to successfully market the new interface and convince semiconductor manufacturers of the benefits of Teradyne's new docking interface.

4.4 A Summary of the Problem

There is a need for a better mechanical interface between the ATE testhead and the wafer probing device. This need is consistent with the semiconductor industry's requirements to manufacture devices of smaller line width, more complexity, and higher pin counts. The nature of the ATE industry has made it difficult for engineers in any one company to implement solutions for problems associated with the current generation of testers. The ATE engineers concentrated on electrical testing issues and prober/handler companies focused on the mechanical challenges without significant collaboration between the two groups.

Over time, minor problems have gradually evolved into complex problems that impede efficiency and demand a solution. The problem is being tackled by a joint Teradyne-MIT team that expects to introduce a new mechanical interface to the market in late 1995. Their goal is develop a market for the new mechanical interface as soon as possible. If the engineering team depends on the sale of new test systems, they will have to wait until 1997 or beyond to have a revenue stream large enough to support a world class mechanical engineering team. They would like to develop the market faster by convincing customers with the installed bases to convert to the new mechanical interface. However, about 60% of the industry is still running production of simpler devices and using older equipment. The engineering and marketing teams have to make very tough decisions and are listening to all points of view on how they should present their new kinematic interface to their customers.

4.5. Class Assignment

The objective is to present a sales plan that addresses both the technical advantages of the new mechanical interface and the economic savings that may result from its usage.

1. The class will form three teams. Select your partners so that you can meet outside of class at least twice between now and May 1.

2. Read the case and prepare questions for the Teradyne guests who are coming to class on May 1. We expect to welcome Jim Mahon and Randy Thomae, who are product managers

of the interface group, and Michael Chiu, the mechanical engineer responsible for the design of the interface.

Make sure that you understand well the technical issues. The trade-offs which have been made technically will result in the functional advantages that Teradyne intends to present to its customers. In addition, list the relevant economic and business issues. The customers will not purchase the new interface unless they have confidence that there will be a financial payback. It is your job to obtain from the Teradyne staff the information which you wil need to prepare your proposed sales plan.

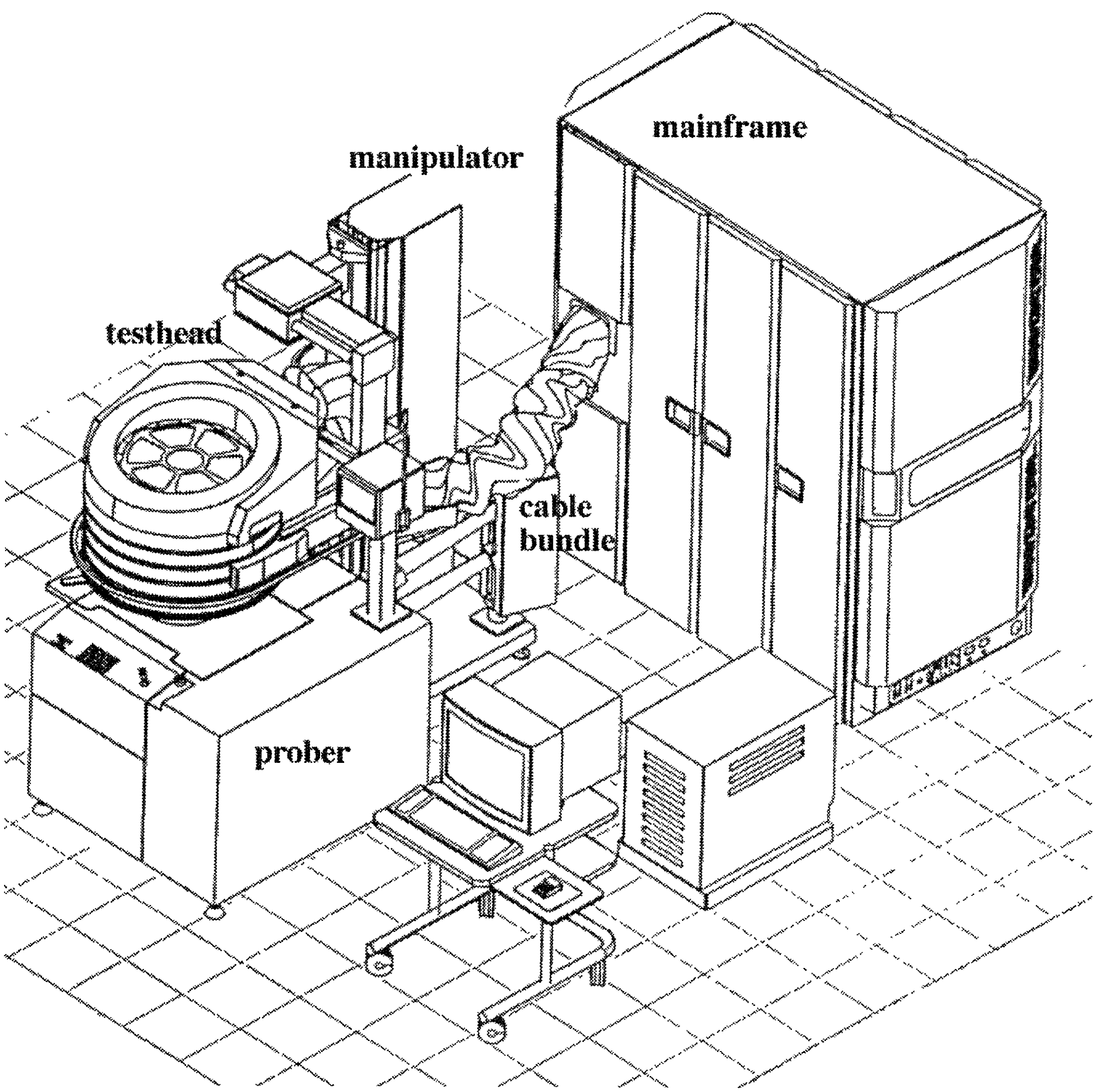
3. Each team will present their sales plan on May 8. Presentations should last about fifteen minutes. A comment and discussion period will follow.

Appendix A

Automatic Test Equipment Setups

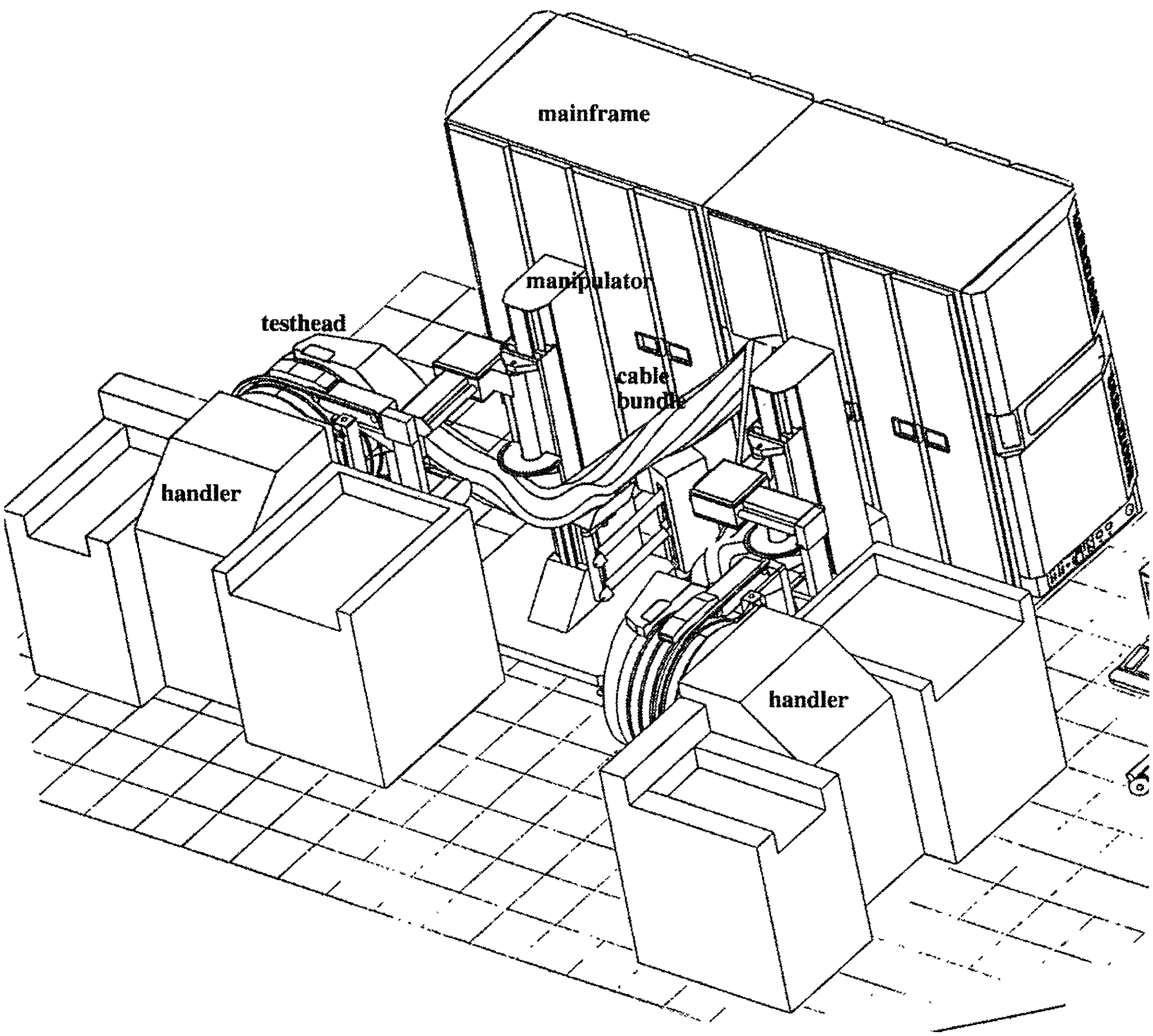
A.1 Wafer Test Setup

The wafers reside in the prober. The testhead is maneuvered by the manipulator and is mechanically docked to the prober. Note the cable bundle extending from the testhead to the mainframe.



A.2 Final Package Test Setup

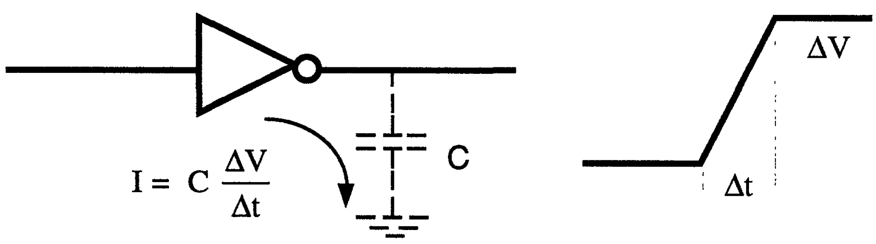
The final packages (or chips) are presented to the testhead by a handler. Note that the testhead is docked to the handler vertically. Some handlers utilize gravity to "drop" the chips in to place for testing. For these setups, the testhead is required to dock to the handler from underneath. Limited access in these situations can make docking difficult and cumbersome.



Appendix B
The Need for Testheads

Is it possible to eliminate the need for testheads altogether? Testheads contain all the circuitry used to send and receive signals to and from the device under test. The current technology requires that the driving and receiving circuitry be as close to the device under test as possible.

Digital complementary metal oxide semiconductors (CMOS) are the dominant logic family in large-scale integrated circuits. The combination of low power dissipation and stiff outputs that swing the full supply range make CMOS logic the family of choice for most digital circuits. With the introduction of CMOS, the circuitry for driving and receiving test signals must be as close to the device under test (DUT) as possible in order to shorten the signal path through wires. The reason is that during transitions, a CMOS output must supply a transient current $I = C\,dV/dt$ to charge any capacitance it sees.

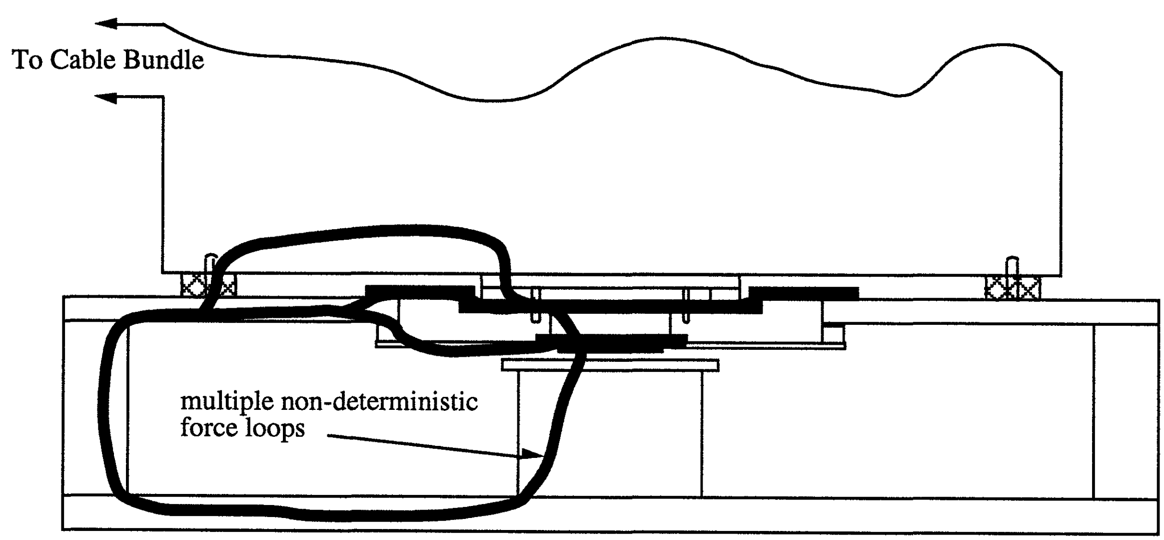


Capacitive Charging Current

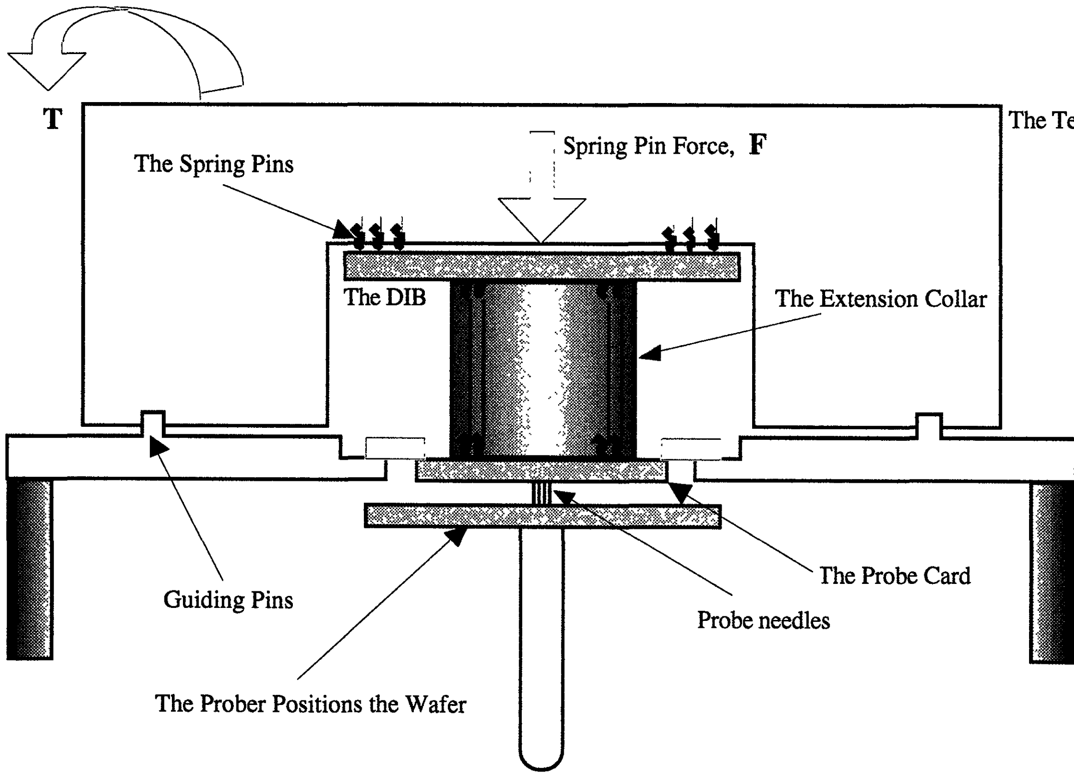
Load capacitance can result from wiring ("stray " capacitance) and from the input capacitance of additional logic being driven. Since the energy stored in a capacitor is $E = 1/2\,CV^2$, and an equal amount of energy is dissipated by the resistive charging circuit, the power dissipated is $P = V^2 fC$ for a switching frequency f. Therefore, in order to keep power consumption at a reasonable level, we must shorten the wire length, thereby reducing the load capacitance, C. Moreover, decreasing C would shorten test time since the CMOS would spend less time charging stray capacitance.

Appendix C
Repeatability

Semiconductor manufacturers spend a significant amount of time docking testheads with handling devices and making sure probe needles are properly aligned with the DUT. However, it sometimes is desirable to decouple the testhead and the handling device. The removal of the testhead is necessary due to the complex nature of the existing devices. Different device interface boards or probe cards might be necessary to conduct different tests on the same type of device. Different setups also are desirable for the testing of different types of devices. Once the testhead is removed from the prober, the guiding pin system will not allow a 100% repeatable dock of the testhead. When the testhead is docked to the prober, the probe card experiences several different forces. Since the testhead can not be repositioned in a deterministic manner, multiple non-deterministic and non-structural force loops are created. This means the forces on the probe card will change. If the forces are sufficiently different, the probe card can deflect enough so that the probe needles will move relative to the DUT.

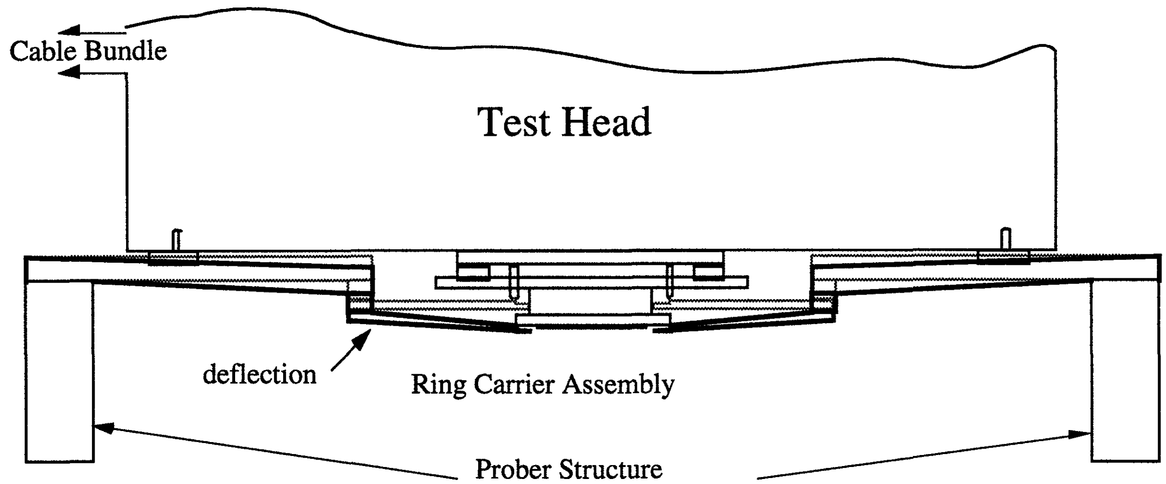


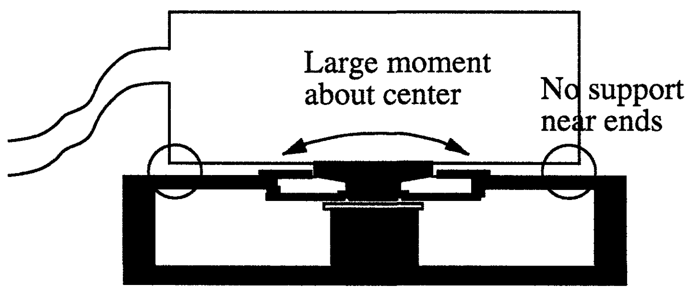
Sources of unwanted forces are: (1) the cable bundle which attaches the testhead to the main frame; (2) the spring pins used to achieve communication between the interface components; and (3) the unsupported weight of the testhead. The cable bundle can weigh 450-1400 pounds. It is very inflexible as it can be as large as 10 inches in diameter. The bundle hangs from the testhead and, hence, applies a torque, T. Due to inflexibility, the cable exhibits the "hysteresis effect". The torque may change after the cable is moved even if it was returned to the same position. Changes in these forces can cause small deflections in the probe card. Therefore, some of the probe needles might lose contact with the wafer/chip or severely scratch the bond pads due to the distortion caused by the different force, F, and torque, T, on the system.



As the testhead is docked, spring pins are compressed (2 ounces of compression force for each pin) against contact pads on the DIB and probe card. In order to achieve the necessary electrical connections, the testhead can exert up to 300 lbs. of force on the top plate of the prober and can cause deflections in the probe card.

The deflections caused by the deformation of the top plate are amplified by the testhead support system. The testhead is guided into rough position by the large dowel pins located on the exterior perimeter of the prober top plate. However, these pins do not support the load of the testhead. Instead, the weight of the testhead is fully supported by the interface components such as the DIB and the probe card.





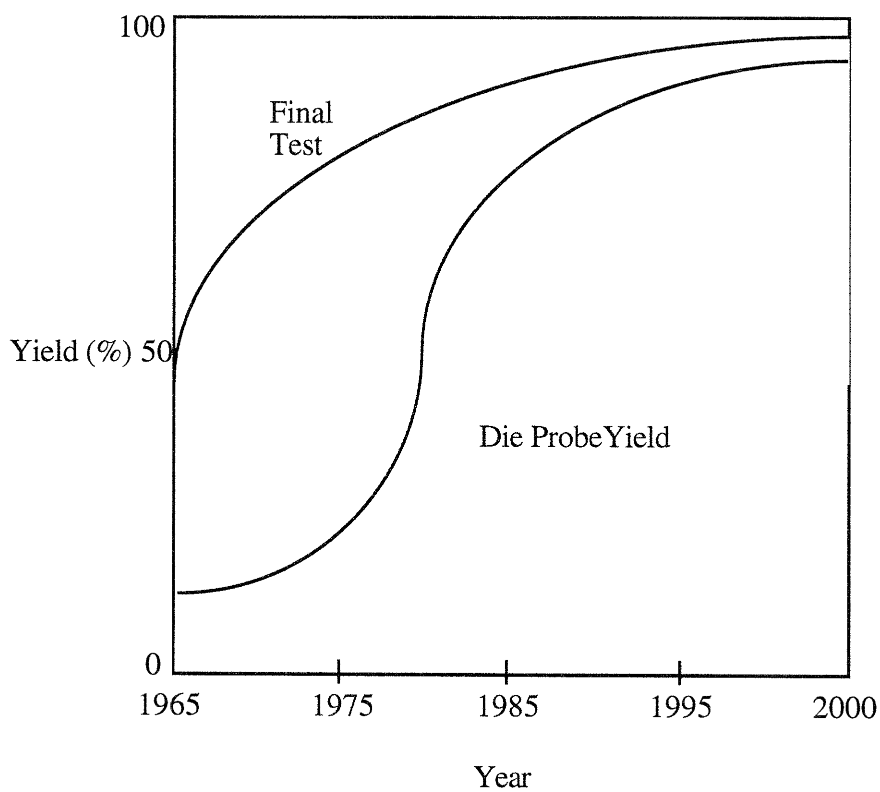
Repeatability requires a docking system which would be indifferent to the effects of these sources of error. A deflection of less than 0.001" is sufficient to require replanarization of the probe card. A docking system using kinematic coupling as the mechanical interface between the testhead and the prober will eliminate these unwanted deflections.

Appendix D
The Importance of Wafer Sort

Thirty years ago, greater emphasis was placed upon final test. Wafer-sort test-limits were guard-banded pessimistically so that many good parts in the marginal guard-band region were discarded in order to obtain high yields at final test.

However, as yields have improved over the years, the value of testing has shifted from the final package stage to the wafer stage of the manufacturing process. Today, die sort yields are as high as 75% as compared to 10-15% in the 1960s. As this trend continues, final test will be relegated purely to sampling procedures to ensure that the process works, not to show whether the device is good or bad. If the process passes the test, the device will pass too.

Yield v. Time



source: VLSI Research, Inc.

Appendix E

Kinematic Coupling Experimental Setup

E.1 Proof of Concept

E.1.1 The Spacestation

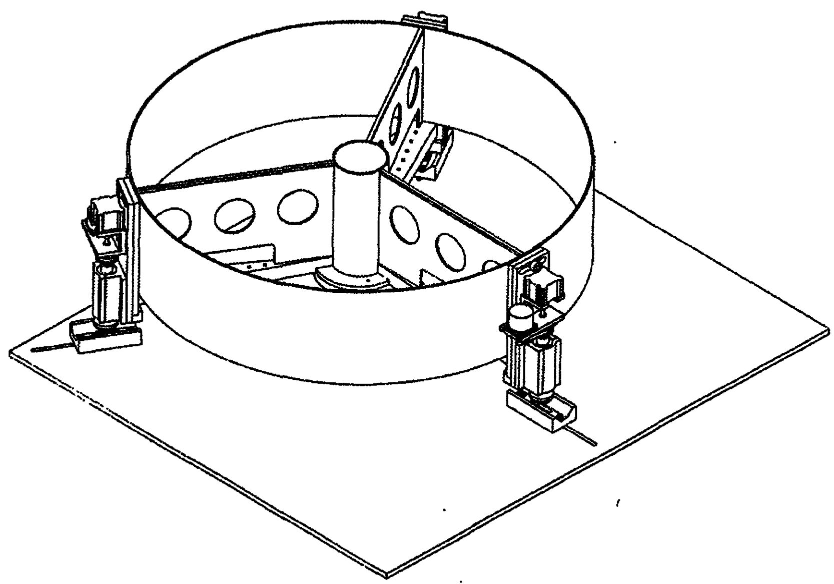


Figure E1: The Spacestation

In order to adapt the concept of kinematic coupling to Teradyne's needs, a proof-of-concept prototype was built. This first prototype was dubbed the "spacestation" by the Teradyne engineers. The spacestation is an aluminum weldment with three kinematic modules. Each kinematic module consists of two halves: the ball assembly and the V-groove. The aluminum V-grooves are mounted on an aluminum plate (top plate) as shown in Figure E1. The ball assembly consists of a steel ball and a preload mechanism. The preload mechanism uses a T-bolt in conjunction with an air cylinder to pull the V-groove and the ball assembly together. The air supply provides a preload of 60 psi.

The kinematic module was designed to have adjustable z-height. The height adjustment system is computer controlled and consists of a dc motor, a belt drive system used to drive the leadscrew, and a linear bearing which incorporates recirculating balls on a round shaft (e.g., a Ball Bushing from Thomson Industries). The leadscrew nut is epoxied to the inside of the round shaft which is an extension of the steel ball (Figure E2).

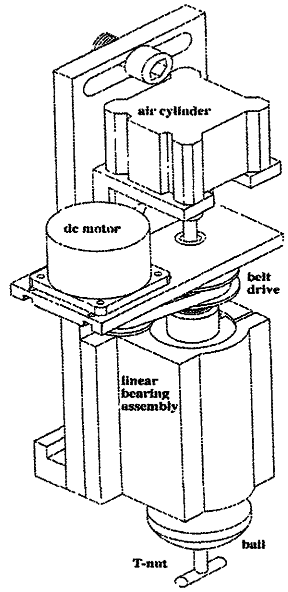


Figure E2: The Module

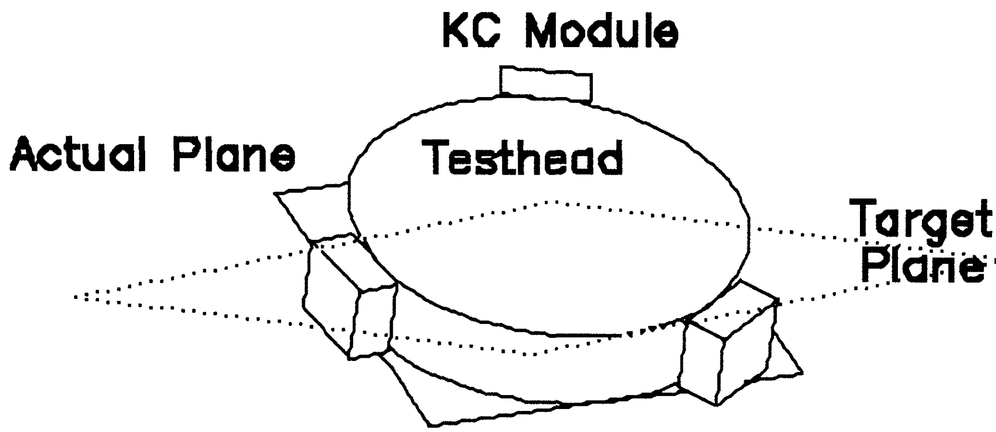
E.1.2 Preliminary Results

Previous experiments have shown that kinematic arrangements such as the three ball/three V-grooves can provide repeatability of better than 10 micrometers. A brief set of experiments using the spacestation demonstrated repeatability measurements on the order of 0.001". Upon closer examination, excessive wear in the aluminum grooves was observed. It would be possible to achieve an order of magnitude improvement in the results by using hardened stainless steel balls and grooves and a preload mechanism capable of exerting higher magnitude forces.

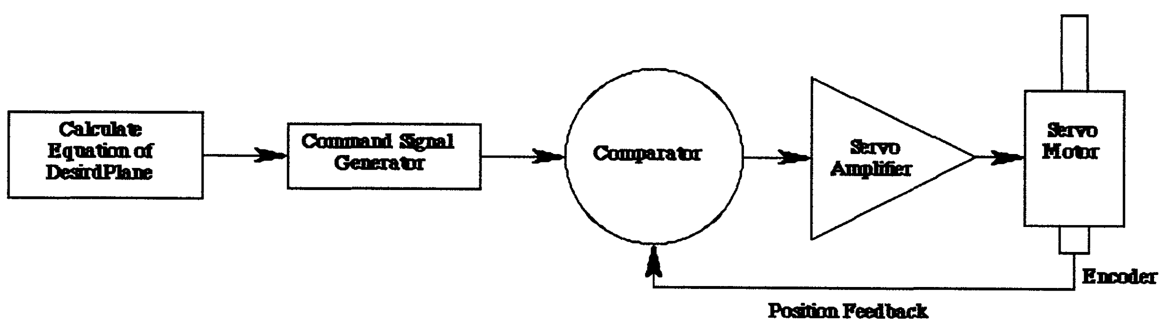
E.1.3 Autoplanarization

Currently, it is common for the probe card and the DIB to reside on the prober before the testhead is docked. In the future, situations might arise in which the probe card is attached directly to the testhead. In the former case, it is desirable that the pogo pins exert a distributed force uniformly across the DIB board once the testhead is docked. This will minimize deflections of the probe card. This requires that all the pogo pins lie in a horizontal plane. If the probe card is attached to the testhead, it is desirable that all the probe needles be planar to the wafer.

In either scenario, the desired objectives are attainable through a routine known as *autoplanarization.* When the testhead is docked to the prober, three imaginary points on the testhead constitute a plane. The objective of the autoplanarization algorithm is to calculate the equation of the present plane and to adjust the z-height of the three kinematic modules until the three imaginary points lie in a desired plane (e.g., the horizontal plane). For example, it is conceivable to determine the x,y, and z coordinates of three probe needles and calculate the equation of a plane. The appropriate combination of z-height adjustments of the KC modules will ensure that the three probe needles lie in the horizontal plane and are planar to the wafer.



An autoplanarization algorithm was implemented using a PC-based closed-loop servo system represented by the following schematic:



The servo system was implemented using a universal motion interface board (UMI 4A) form NuLogic, Inc. and a servo amplifier mounting card (MC3X series) from Advanced Motion Controls (Figure E3). Nulogic provides a friendly user interface based on

LabView which is a PC-based virtual instrument software package. The servo motors and the corresponding encoders were supplied by Maxon, Inc.

Figure E3: Motion Control System

The equation of the desired plane was calculated using three data points acquired from the three Sony Magnescale sensors mounted toward the center of the spacestation. Magnescales are magnetic scales which use a sliding sensing head to detect sine and cosine waves from a magnetically recorded scale. The scale is typically a wire imprinted with numerous north/south pole pairs. These sensors have an accuracy of 0.002 mm.

The Sony sensors indicate the position of the spacestation relative to an aluminum jig plate mounted at the center of the top plate as shown in Figure E4.

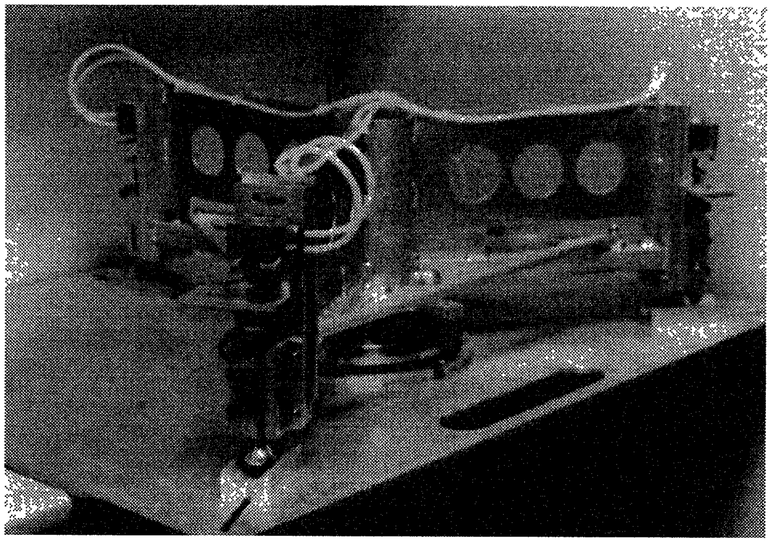
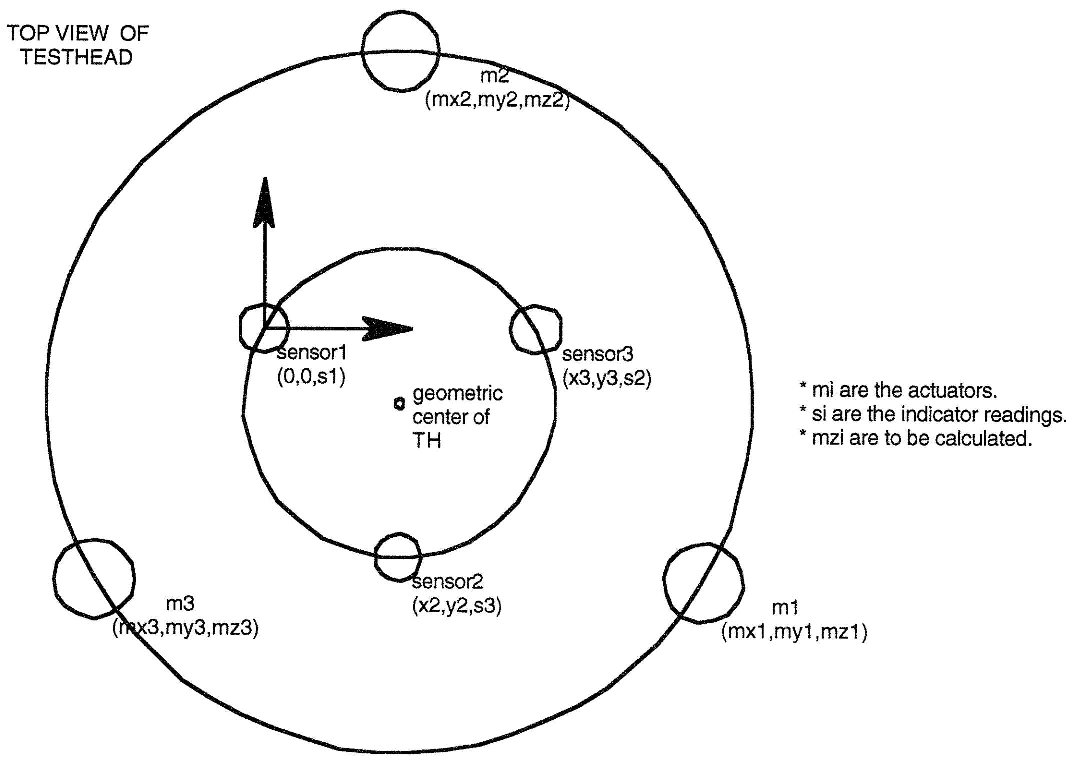


Figure E4: The Spacestation on the Top Plate

In essence, the Magnescales mimic the role of three probe needles on the probe card. In order to planarize the spacestation the following algorithm was implemented:



Once the three sensor readings are known, we write the coordinates of the three Sony Magnescales:

$$\begin{aligned} P_1 &= (0,0,s_1) \\ P_2 &= (x_2,y_2,s_2) \\ P_3 &= (x_3,y_3,s_3) \end{aligned}$$

These points form a plane of the form Ax+By+Cz+D=0.

Using the points P_i, we write:

$$\begin{aligned} &s_1.C + D = 0 \\ &x_2.A + y_2.B + s_2.C + D = 0 \\ &x_3.A + y_3.B + s_3.C + D = 0 \end{aligned}$$

If we let C=1, then D=$-s_1$ and we have to solve for A and B.

$$\begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \end{bmatrix} . \begin{bmatrix} A \\ B \end{bmatrix} = \begin{bmatrix} s_1 - s_2 \\ s_1 - s_3 \end{bmatrix}$$

Therefore,

$$\begin{bmatrix} A \\ B \end{bmatrix} = \begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \end{bmatrix}^{-1} . \begin{bmatrix} s_1 - s_2 \\ s_1 - s_3 \end{bmatrix}$$

$$\begin{bmatrix} A \\ B \end{bmatrix} = \frac{1}{x_2 y_3 - y_2 x_3} \begin{bmatrix} y_3 & -y_2 \\ -x_3 & x_2 \end{bmatrix} . \begin{bmatrix} s_1 - s_2 \\ s_1 - s_3 \end{bmatrix}$$

This determines the coefficients of the plane equation Ax+By+Cz+D=0. In order to calculate the desired z-height of the kinematic modules, the (x,y) coordinates of the actuators are used and the target position is calculated for each module as follows:

z=(Ax+By+D)/C

E.2 The Alpha Prototype

The next step in the implementation of the kinematic coupling concept was to assemble and evaluate an alpha prototype (Figure E5). The alpha coupling consists of a hardened steel ball and groove. It has an automatic latch mechanism as described in Section E.2.1 as well as a z-height adjustment mechanism described in Section E.2.3.

A test jig was prepared to allow Teradyne to evaluate the performance of the kinematic coupling interface. Preparation of the experimental setup involved the completion of the control electronics for latch/preload sensing, building a mockup prober/handler structure, and mounting the kinematic modules on Teradyne's next generation testhead.

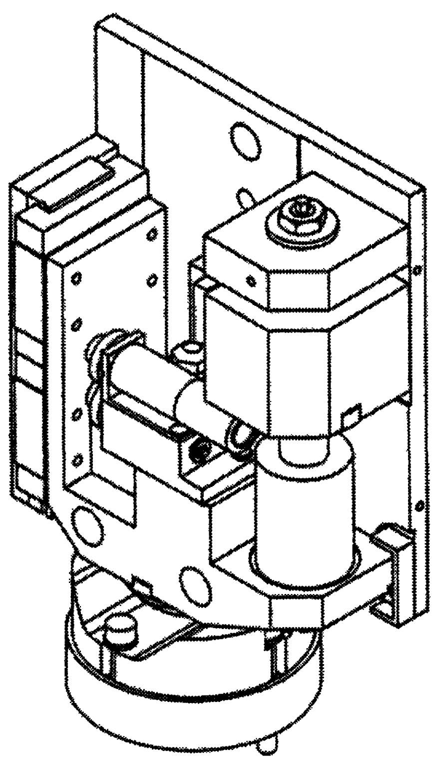
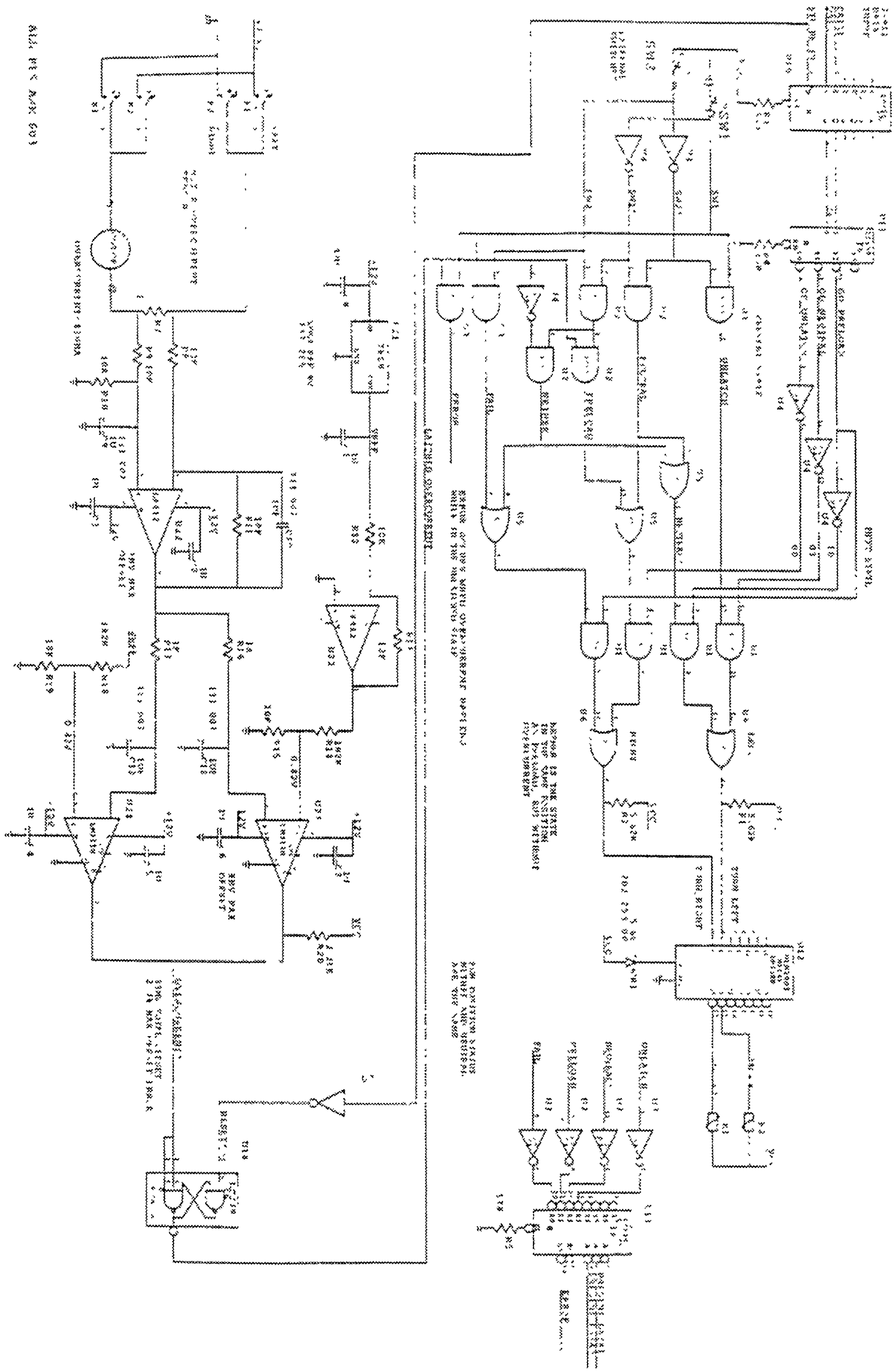


Figure E5: The Alpha Prototype

E.2.1 Control Electronics



In developing the new mechanical interface for its next generation test systems, Teradyne's goal was to implement a reliable and user friendly docking system. The spacestation modules utilized a T-bolt which had to be engaged manually before preloading the system. The alpha prototype facilitates the docking sequence for the operator by incorporating an automatic latching system as demonstrated in Figure E6.

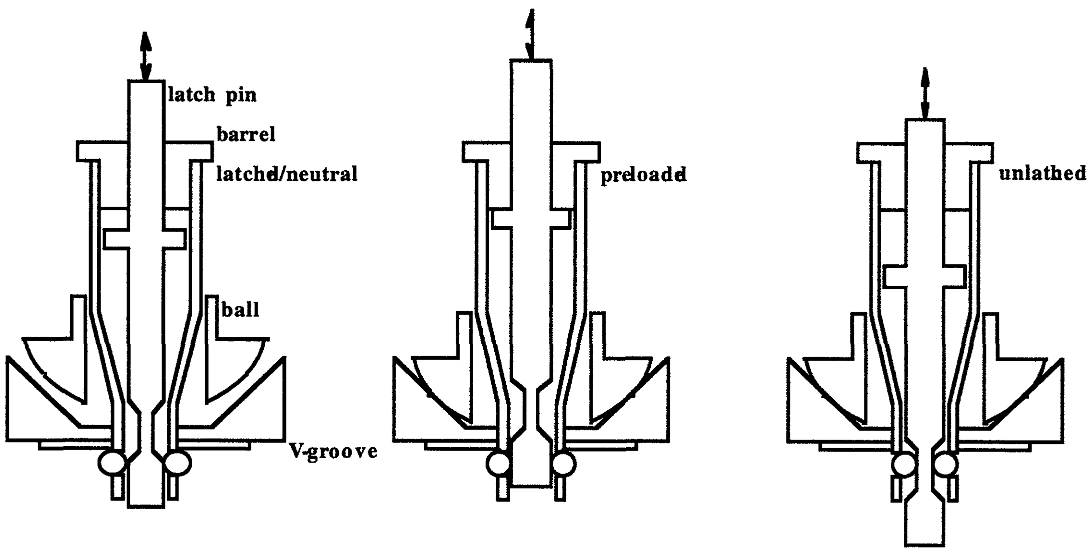
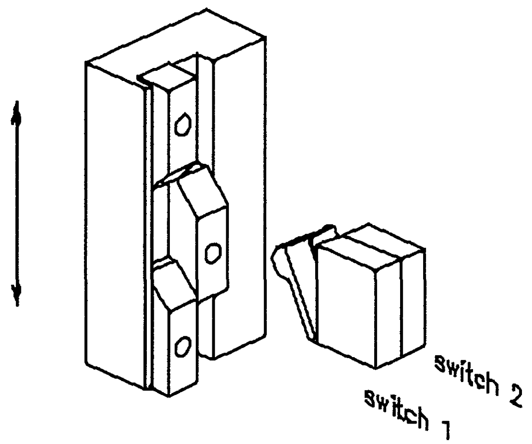


Figure E6: The Latch/Preload Mechanism

Once the ball assembly is latched to the V-groove, the preload mechanism can be activated with the touch of a button and the system will dock automatically by pulling the testhead and the prober together. This occurs when the latch pin is driven upward by a dc motor, thereby pulling the ball and the V-groove together. In order to notify the operator of the status of the interface, control electronics were developed with the assistance of a Teradyne's electrical engineer. At any given time, the coupling can be in any of the following three states:

- Neutral: The coupling must be in this state before the operator can latch the ball assembly to the V-groove.
- Preload: The ball and the V-groove are preloaded against each other.
- Unlatch: The coupling must be in this state before the operator can undock (e.g. separate the ball assembly from the V-groove).

The states are determined by using two mechanical microswitches in conjunction with three cams mounted on the latch pin (Figure E7). As the latch pin is driven up or down, the cams trigger the microswitches as shown in the logic table below. The preload state is reached when switch 1 is OFF, switch 2 is ON, and the over-current sensor (implemented in the electronics) is triggered. The electronics were debugged and tested. The next step would be to evaluate the performance of the completed modules.



state	switch 1	switch 2	motor
unlatch	ON	OFF	RUN
neutral	OFF	OFF	RUN
preload	OFF	ON	Over Current
preload fail	ON	ON	RUN/Over Current

Figure E7: Cams and the Microswitches

E.2.2 The Experimental Setup

E.2.2.1 Mounting the Kinematic Coupling Modules

At this point, Teradyne's next generation testhead, code named the "Hydra," was in the early stages of development. However, an aluminum weldment of the testhead which would be used to cast all subsequent Hydra testheads was completed. Six positions were identified as possible mounting locations for the kinematic coupling modules. The couplings are represented by the blocks in Figure E8. The openings on the perimeter of the testhead are necessary for airflow in order to cool the electronics. Note that the couplings located in the front and the back would block the airways if mounted directly on to the testhead.

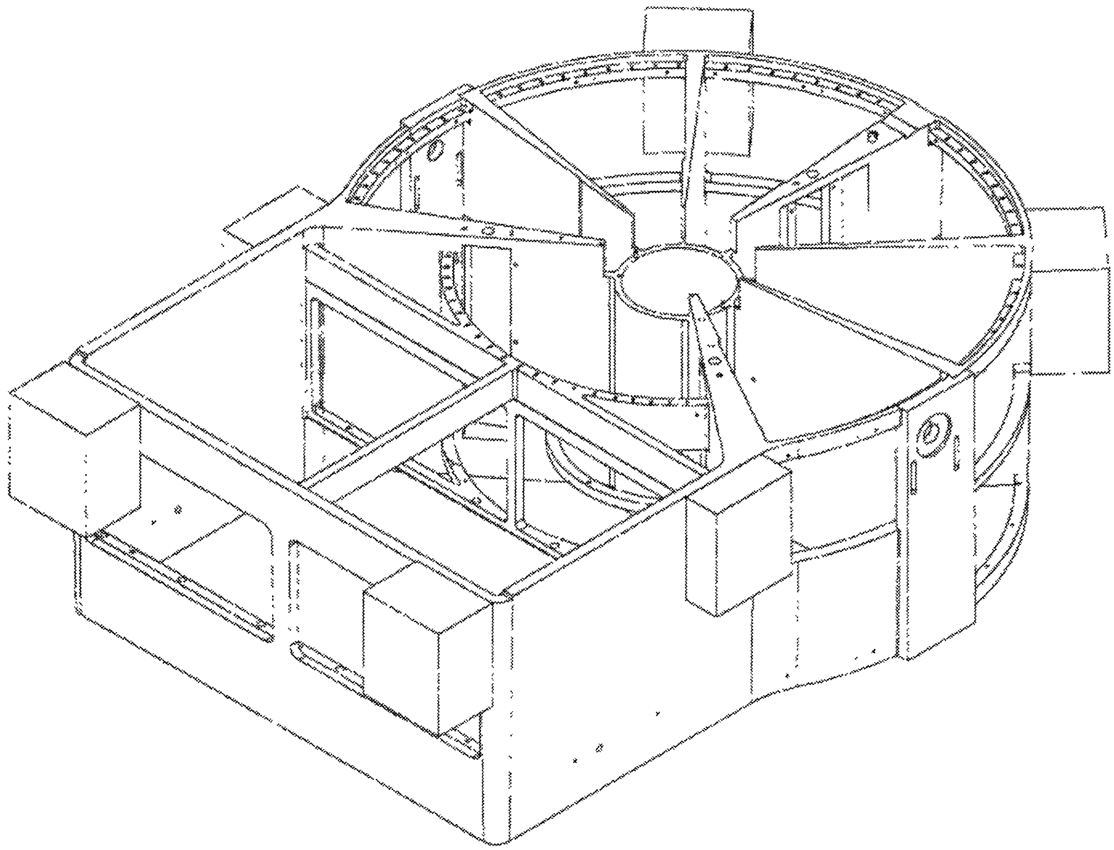


Figure E8: The Hydra

In order to resolve the airflow issue, the modules were mounted on flanges designed to provide structural support for the couplings and to allow airflow in to the testhead (Figure E9). The airflow around the flanges was modeled by Teradyne experts and was deemed acceptable.

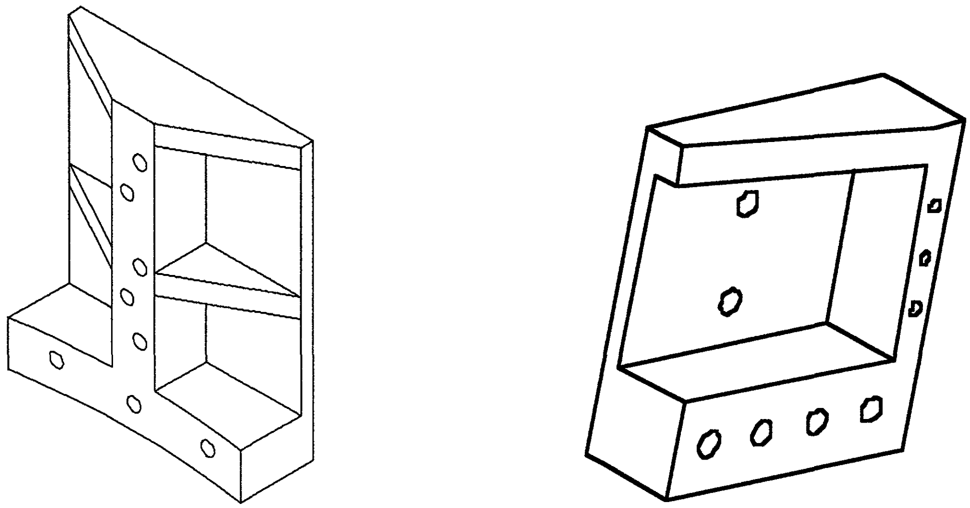


Figure E9: The Kinematic Coupling Testhead Mounts

E.2.2.2 The Measurement system

A prober/handler mockup was constructed from aluminum extrusions (Figure E10). The weldment on the underside of the top plate serves as structural reinforcement necessary to minimize any unwanted deflections since evaluation of the interface involves submicroinch measurements.

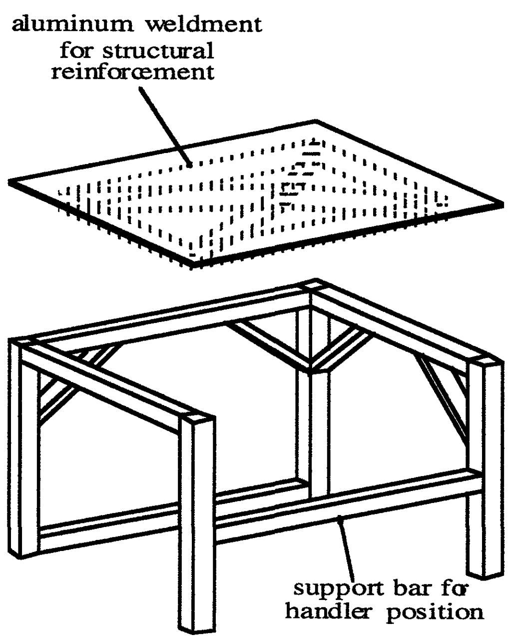


Figure E10: The Prober/Handler Mockup

The V-grooves were mounted on the top plate and a mockup cable bundle was attached to the testhead to simulate actual test conditions as shown in Figure E11.

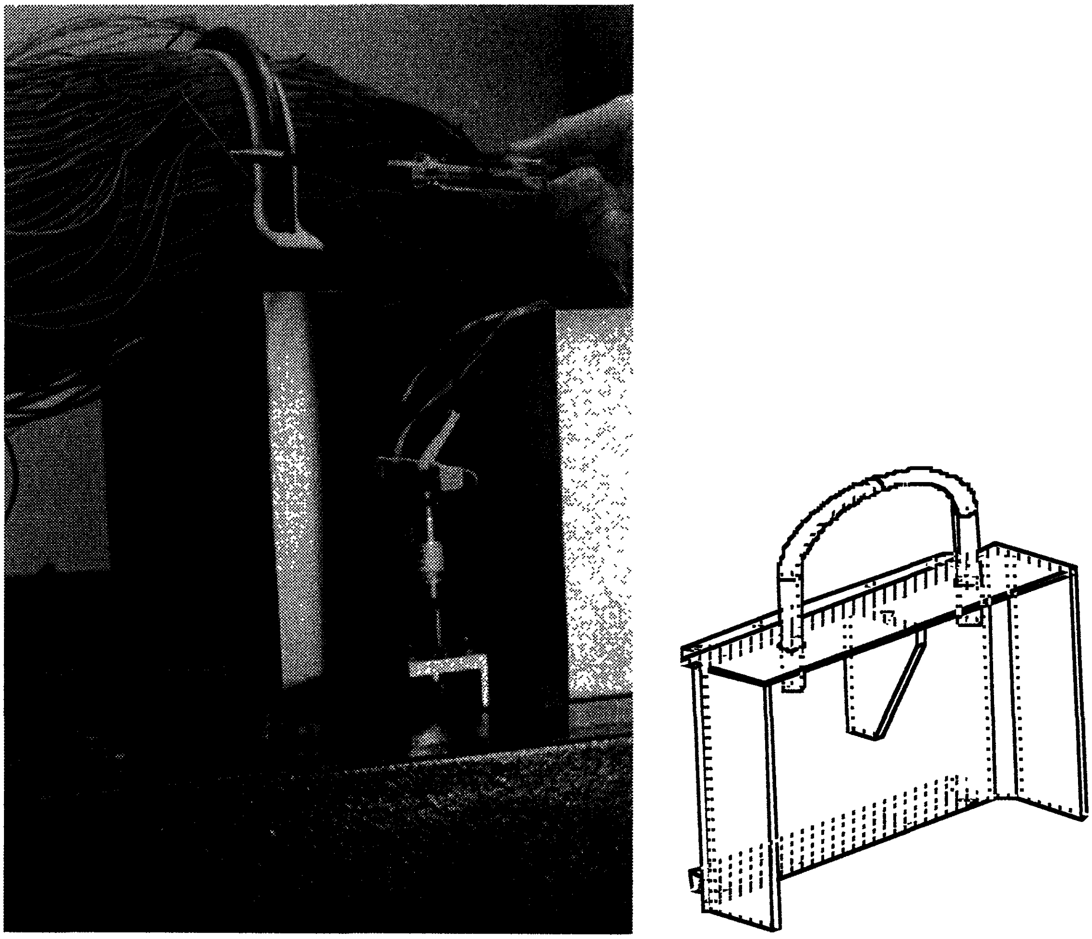


Figure E11: The Cable Bundle

Figure E12 shows the mockup prober structure, the Hydra testhead, the cable bundle, one of the kinematic coupling modules and its corresponding V-groove, and digital indicators used for repeatability measurements.

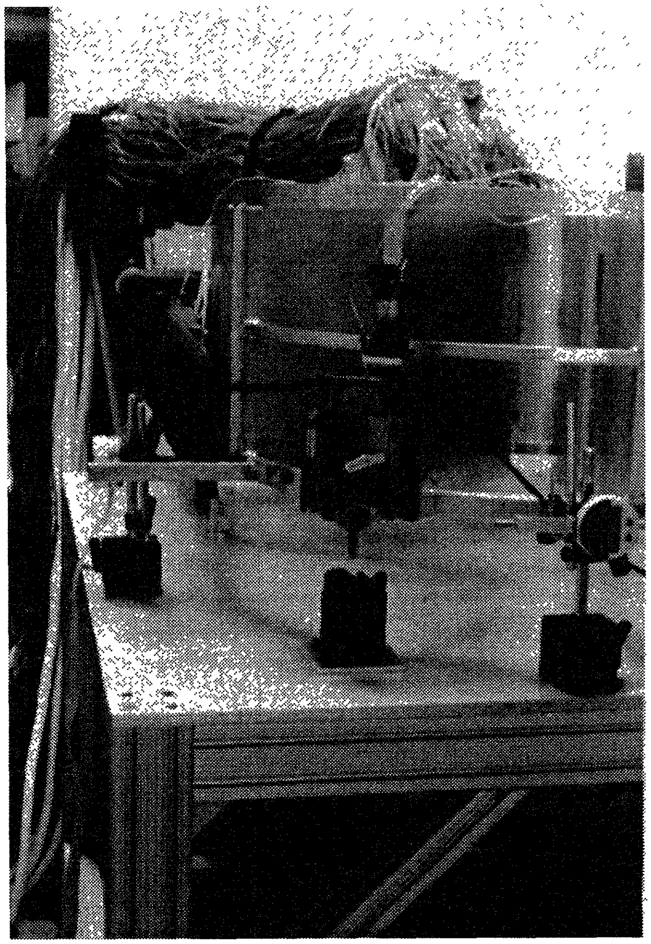


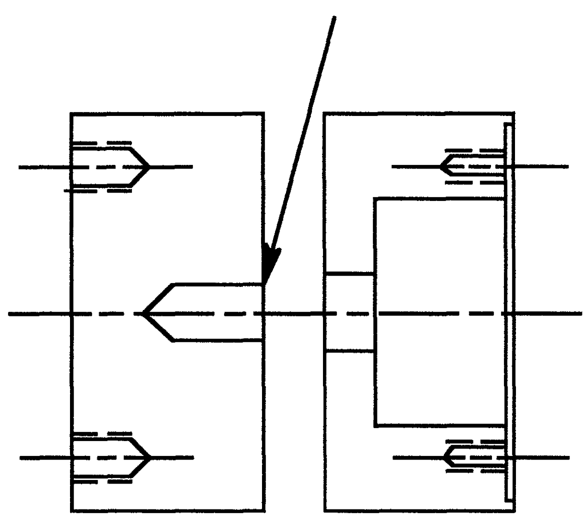
Figure E12: The Setup

Note that the V-grooves are mounted on steel spacers (Figure E13). The spacers serve two functions:

- Some final package test applications require that the testhead be docked to the handler from underneath. In order to simulate this situation, the top plate is flipped and the testhead is docked from underneath the mockup prober/handler structure. If the V-grooves are not mounted on the spacers, the manipulator arms would hit the aluminum extrusion before the docking sequence is completed.

Figure E13: The V-groove Mounted on the Spacer

• The spacers consist of two separate halves. The top half contains a clearance hole and the bottom half contains a tapped hole for a socket head screw. The screw can be accessed through the hole in the center of the V-groove.



The x-y location of the V-groove can be adjusted by loosening the screw, moving the top half of the spacer as desired, and retightening the screw. Adjustment of the V-grooves is necessary to compensate for manufacturing tolerances. For example, if the kinematic modules are not bolted on their ideal x,y coordinates on the testhead, the pogo pins might not properly align with the bond pads on the DIB. The x-y adjustment of the V-grooves allows the operator to reorient the testhead as necessary.

The Sony Magnescales were used to obtain planarity measurement. Figure E14 shows a Magnescale mounted on the testhead. The three positions not occupied by the modules were used to mount the sensors. Note that the Magnescale shown is mounted on

Figure E14: The Sony Magnescale

the flange designed to mount the kinematic module.

The sensor readings can be utilized to determine the repeatability of the interface in z, tumble (rotation about the x-axis), and twist (rotation about the y-axis). As described in Section 1.3, the sensor readings can be used to determine the equation of the plane the testhead lies in. Once the equation of the plane is known, the repeatability in z height can be measured at the testhead's geometric center (gc). Using the engineering drawings, the exact x-y coordinates of the gc is determined. Using the plane equation, the z-height of the gc relative to the horizontal plane can be calculated. We denote this as z_0.

The repeatability in tumble can be calculated using the following formula:

$$\theta_{tumble} = \tan^{-1} \frac{z_{\#3} - z_0}{y_{\#3}}$$

Where $z_{\#3}$ is the z-coordinate of a point (A) along the tumble axis and is calculated using the plane equation. $y_{\#3}$ is the distance from the gc to point (A).

The repeatability in twist can be calculated similarly as follows:

$$\theta_{twist} = \tan^{-1} \frac{z_J - z_0}{y_J}$$

Where y_j is the distance from the gc to a point along the tumble axis.

In addition to repeatability measurements in planarity, digital indicators mounted on the top plate were utilized to evaluate repeatability of the kinematic interface in x, y, and theta. Figure E15 shows one of three Mark V digital indicators from Fowler. These indicators have an accuracy of 0.0002" and a repeatability of 0.0001". In order to avoid inflicting any damage to the indicator's spindle, a retraction mechanism was designed and mounted on the indicator. The retraction mechanism consists of a retractor lever and a cylindrical Alnico magnet used to keep the spindle retracted while the testhead is docked or undocked. Once the testhead is docked, the spindle is released manually and allowed to make contact with a steel "paddle" bolted to the testhead. The paddle was designed so as to deflect less than 0.0005" when in contact with the indicator's spindle. The spindle exerts 0.43 lbs. of contact force.

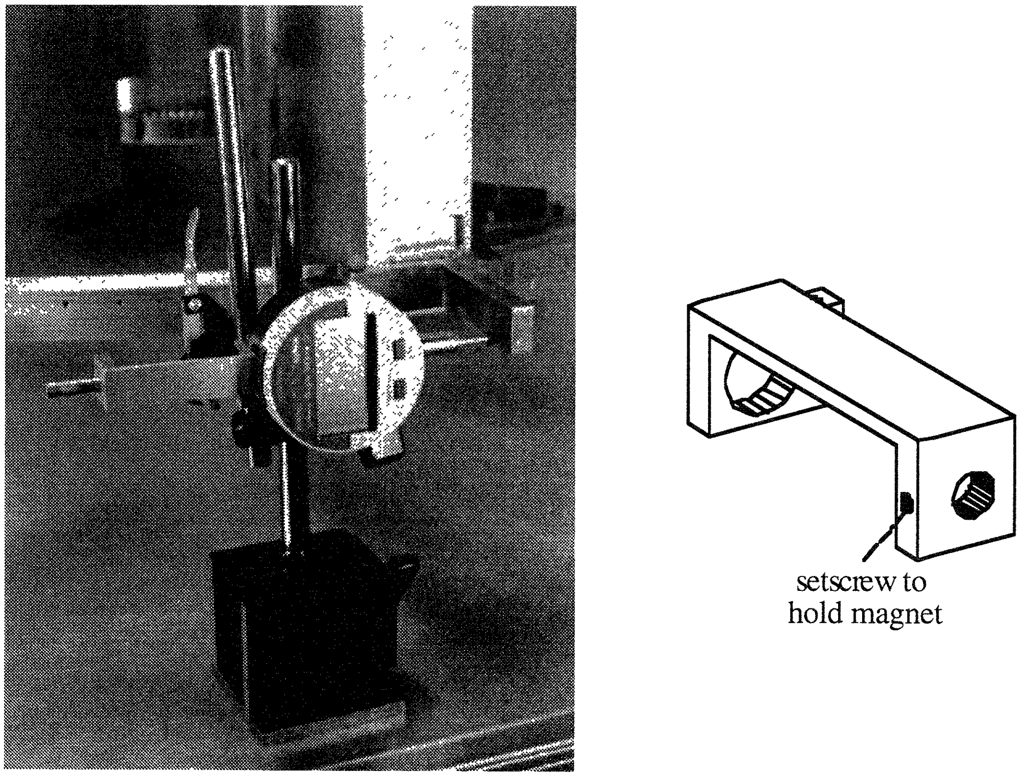


Figure E15: The Fowler Indicator

The digital indicators were mounted on magnetic stands and arranged as shown in Figure E16. Repeatability in x, y, and theta can be measured using the following formulas.

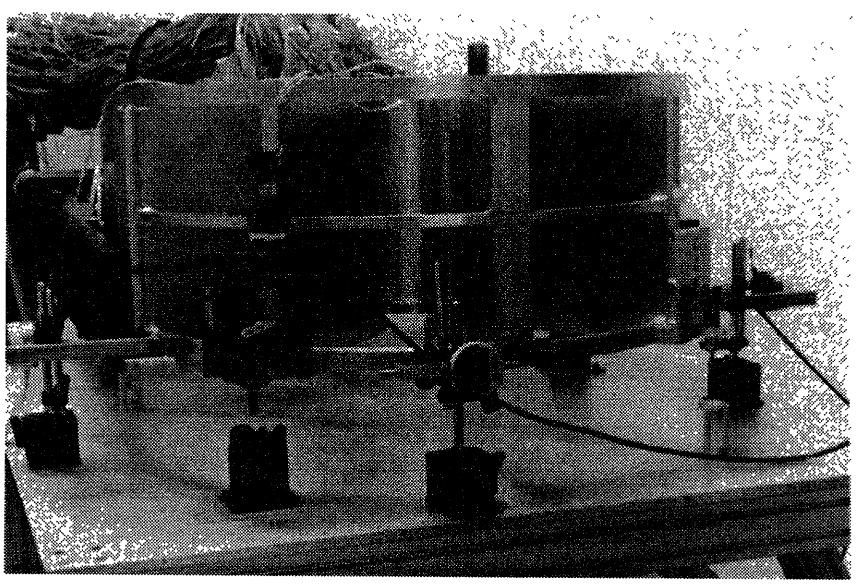
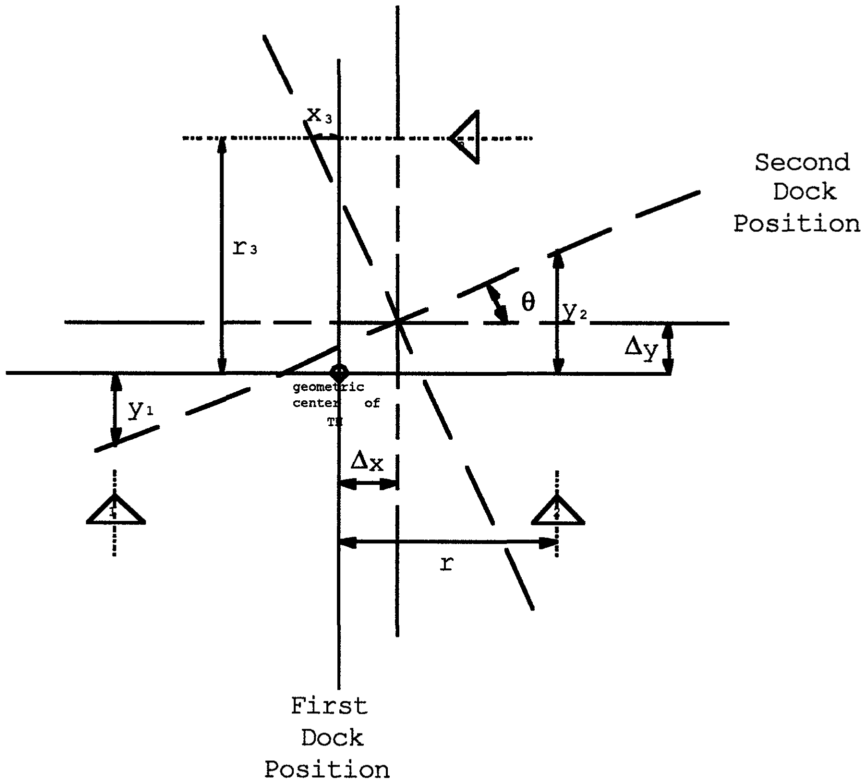


Figure E16: The Indicator Layout



From sensor1,

$$(r+\Delta x)\theta-\Delta y=y_1 \quad (A)$$

From sensor2,

$$(r-\Delta x)\theta+\Delta y=y_2 \quad (B)$$

From sensor3,

$$(r_3-\Delta y)\theta-\Delta x=x_3 \quad (C)$$

Where y_1, y_2, y_3 are the digital indicator readings.

We want to calculate $\Delta x, \Delta y, \theta$.

From (C), we write

$$\Delta x = (r_3 - \Delta y)\theta - x_3$$

Substituting into (A) and (B) and adding, we get

$$\theta = \frac{1}{2r}(y_1 + y_2)$$

Substituting for x, θ in (A), we get

$$\Delta y = \frac{\frac{1}{2}(y_1 + y_2) + (r_3 - x_3)\theta - y_1}{(1 + \theta^2)}$$

E.2.3 Autoplanarization Using the Alpha Prototype

E.2.3.1 Implementation

The alpha module was designed with a z-height adjustment mechanism. As discussed in Section 1.3, this capability allows the operator to either planarize the testhead relative to the DIB or planarize the probe needles to the wafer in cases where the probe card might be directly mounted on the testhead. Recall that the height adjustment mechanism of the spacestation module lies along the same axis as the preload mechanism. This was not achievable for consequent design iterations because an automatic latch/preload mechanism was implemented as described in Section E.2.1. Figure E17 shows the height adjustment mechanism implemented on the alpha prototype. Vertical motion is achieved by using a rolling element linear motion bearing (linear guide). Note the use of a preload nut to eliminate any backlash in the leadscrew. The leadscrew is supported by a thrust bearing and z adjustment is achieved by manually turning the leadscrew.

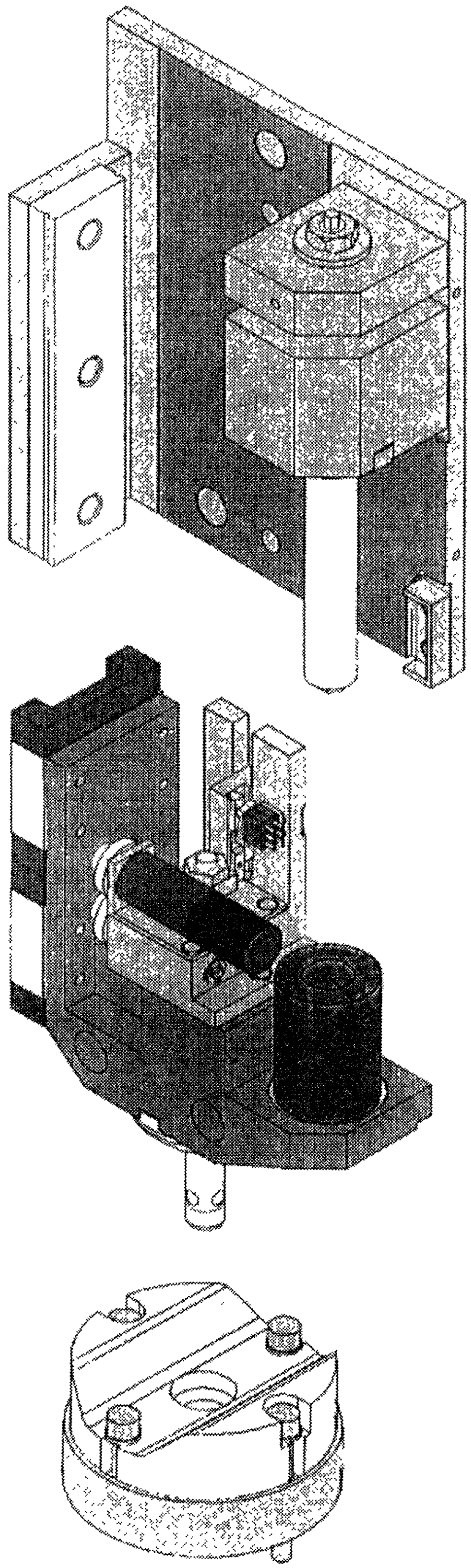
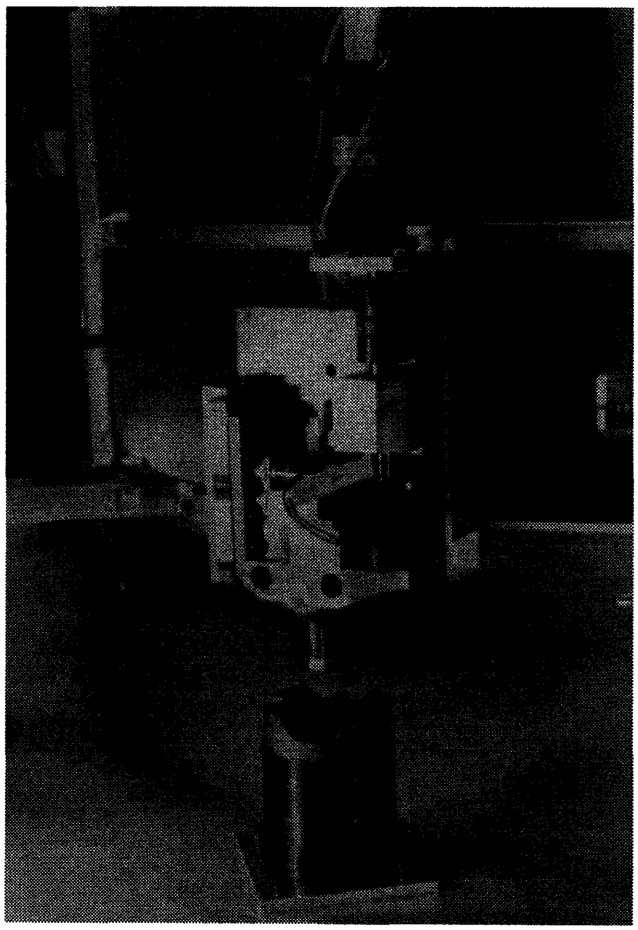


Figure E17: Z-height Adjustment Mechanism

The first kinematic interface sold by Teradyne would allow the operators to manually planarize the testhead. The next generation of the modules would incorporate motorized z-height adjustment for autoplanarization. In order to implement autoplanarization on the alpha prototypes, they were modified as shown in Figure E18. A Maxon dc-motor was mounted on the module and a helical flexible coupling was used to drive the leadscrew. The use of the flexible coupling allows for greater radial and angular misalignment of the motor spindle with the leadscrew.



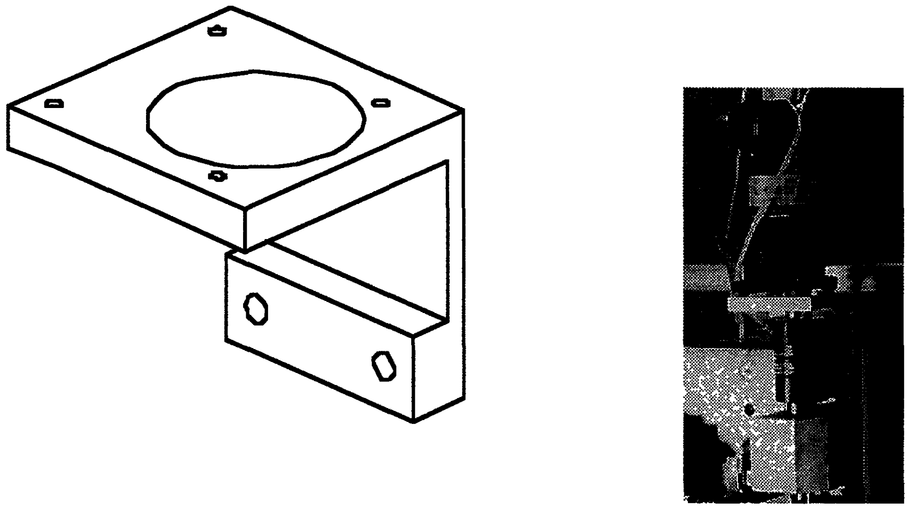


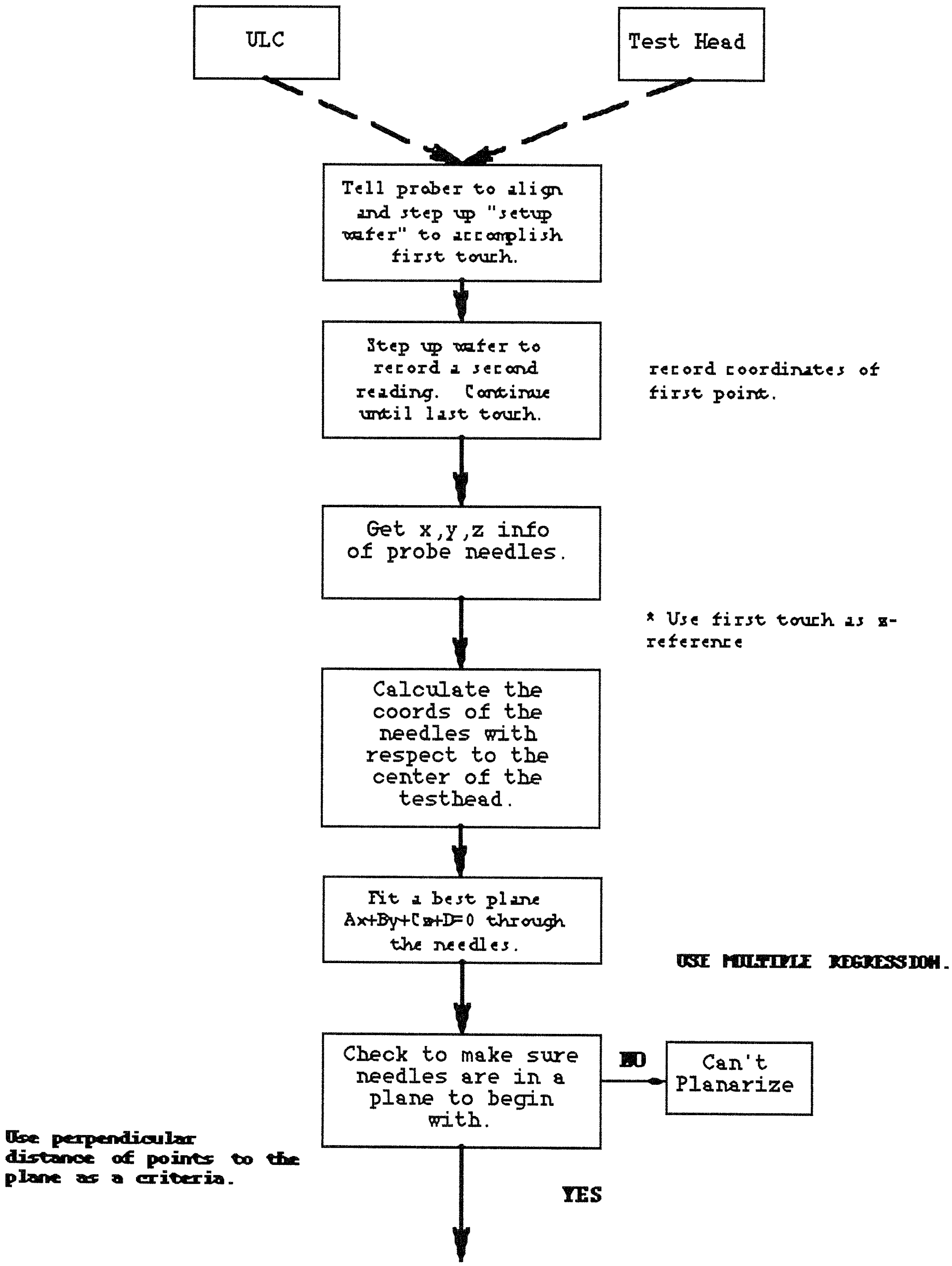
Figure E18: The Modified Alpha Modules

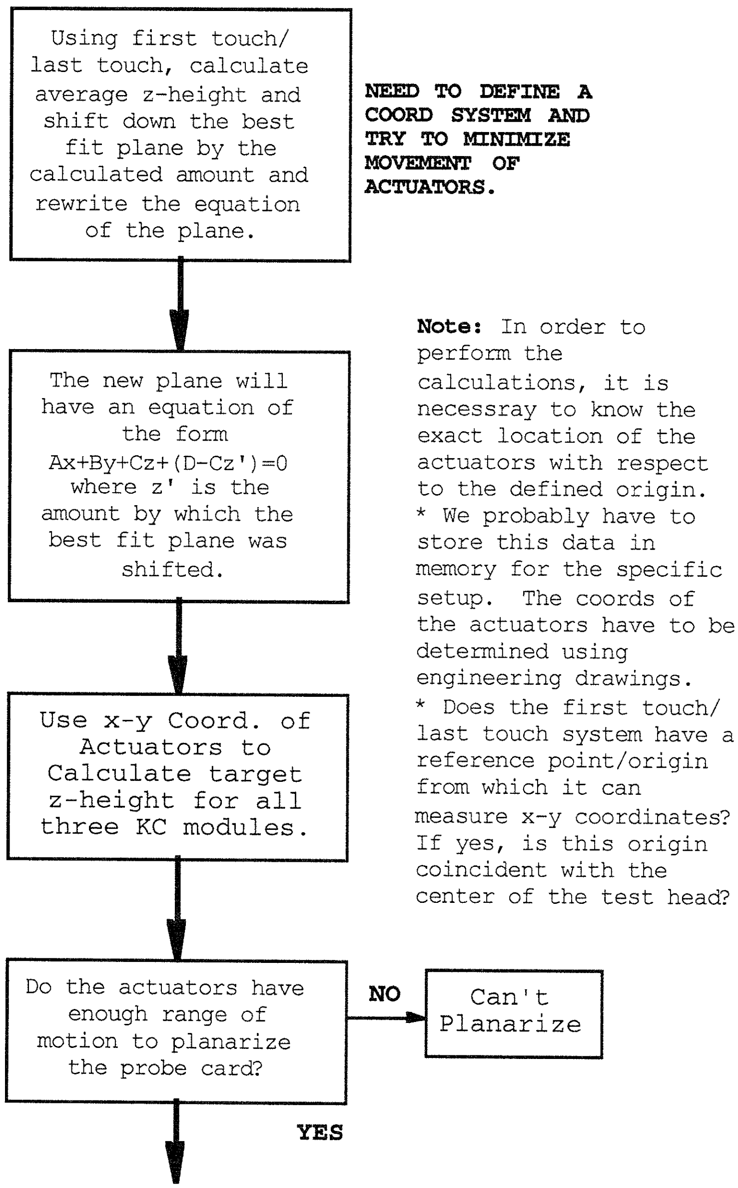
The implemented solution was for proof-of-concept and customer demonstrations only. Due to space constraints, an actual implementation of autoplanarization does not allow the motor assembly to protrude beyond the edges of the mount plate. The autoplanarization algorithm implemented on the spacestation was utilized and proved to be successful.

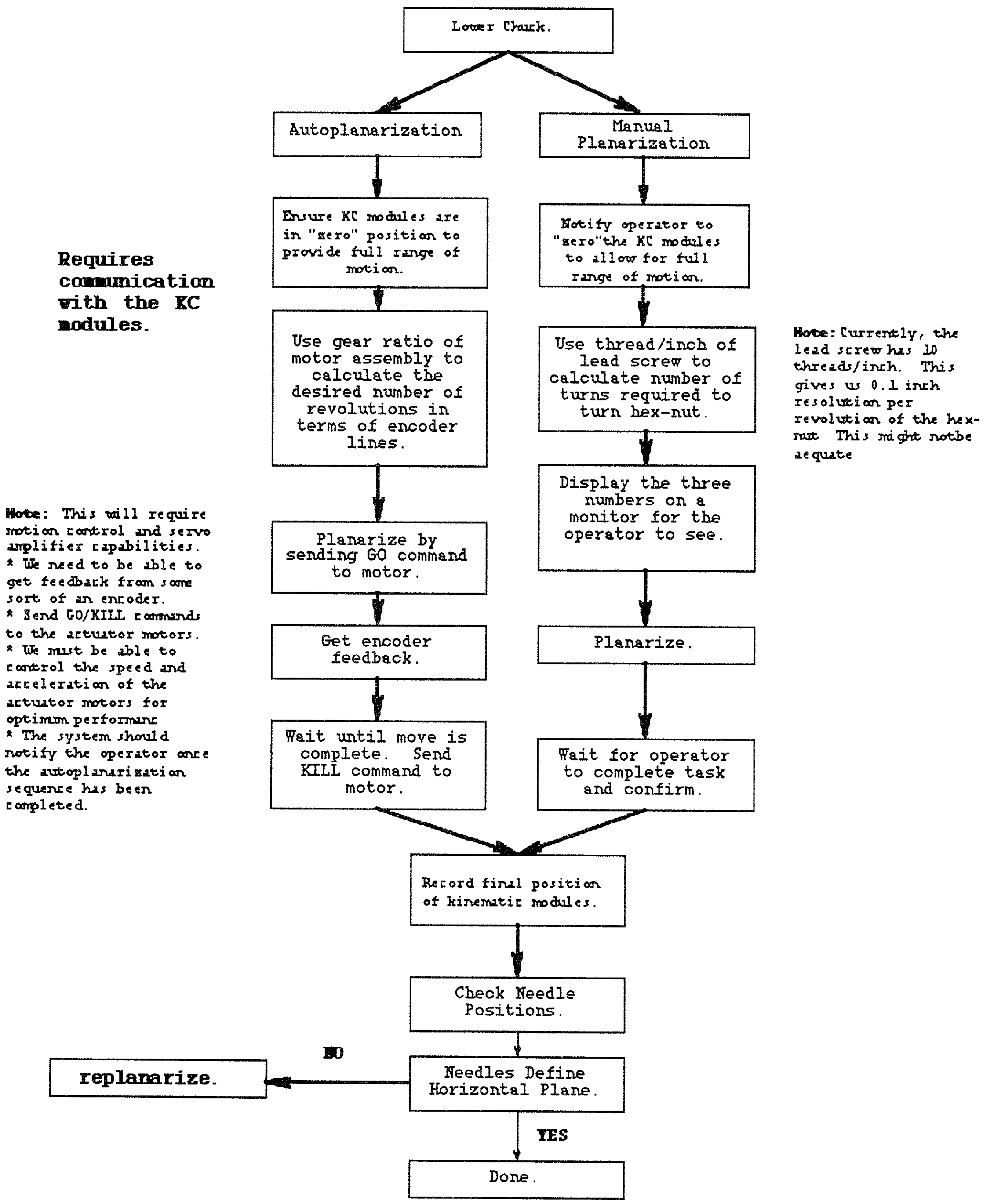
E.2.3.2 Future Considerations

Implementation of the autoplanarization feature on the kinematic interface requires far more sophisticated software than the PC-based data acquisition and motion control system used to evaluate the concept. In order to implement autoplanarization on customer test floors, Teradyne's tester must be able to exchange data with the probe. For example, in cases where the probe card might be mounted on the testhead, the x,y, and z coordinates of the probe needles are required for autoplanarization. This information can be acquired from the prober. This exchange of information can be accomplished by software developed in joint effort between Teradyne and the prober companies. The following flow charts were prepared and presented to the Teradyne Software Engineering Group in an effort to initiate this process.

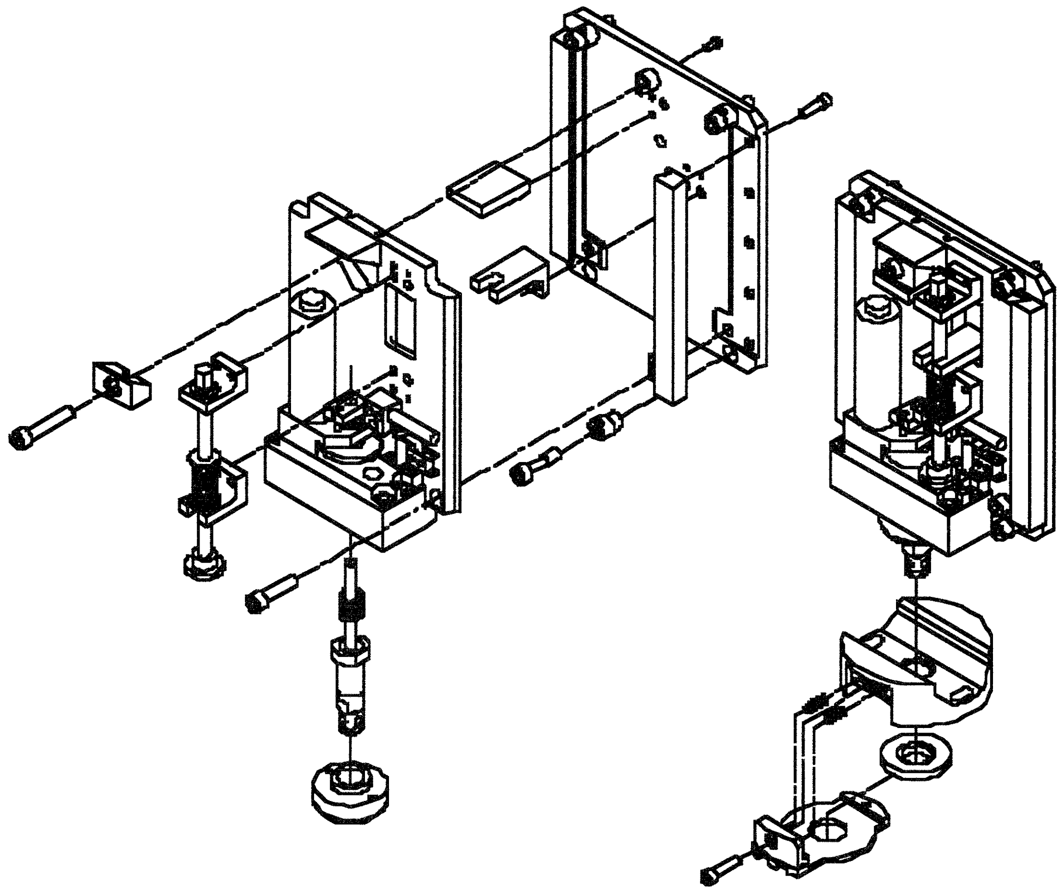
Software Requirements for Planarization Using the KC Module

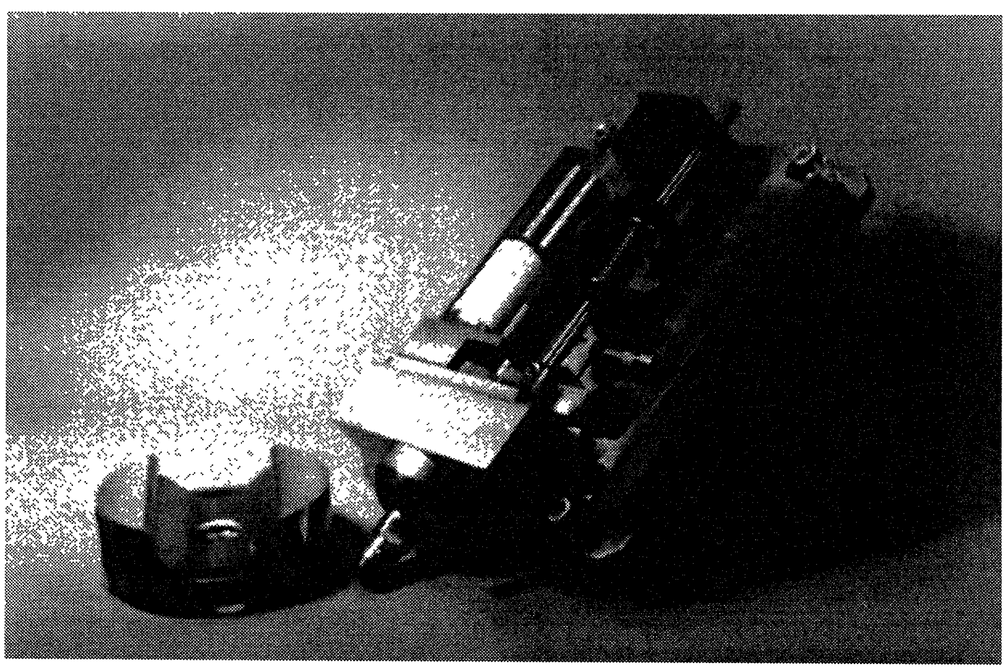



Using first touch/ last touch, calculate average z-height and shift down the best fit plane by the calculated amount and rewrite the equation of the plane.
NEED TO DEFINE A COORD SYSTEM AND TRY TO MINIMIZE MOVEMENT OF ACTUATORS.
The new plane will have an equation of the form Ax+By+Cz+(D-Cz')=0 where z' is the amount by which the best fit plane was shifted.
Note: In order to perform the calculations, it is necessray to know the exact location of the actuators with respect to the defined origin.
* We probably have to store this data in memory for the specific setup. The coords of the actuators have to be determined using engineering drawings.
* Does the first touch/ last touch system have a reference point/origin from which it can measure x-y coordinates? If yes, is this origin coincident with the center of the test head?
Use x-y Coord. of Actuators to Calculate target z-height for all three KC modules.
Do the actuators have enough range of motion to planarize the probe card?
NO
Can't Planarize
YES


Lower Chuck.
Autoplanarization
Manual Planarization
Ensure KC modules are in "zero" position to provide full range of motion.
Notify operator to "zero"the KC modules to allow for full range of motion.
Requires communication with the KC modules.
Use gear ratio of motor assembly to calculate the desired number of revolutions in terms of encoder lines.
Use thread/inch of lead screw to calculate number of turns required to turn hex-nut.
Note: Currently, the lead screw has 10 threads/inch. This gives us 0.1 inch resolution per revolution of the hex-nut. This might notbe aequate
Display the three numbers on a monitor for the operator to see.
Note: This will require motion control and servo amplifier capabilities.
* We need to be able to get feedback from some sort of an encoder.
* Send GO/KILL commands to the actuator motors.
* We must be able to control the speed and acceleration of the actuator motors for optimum performanc
* The system should notify the operator once the autoplanarization sequence has been completed.
Planarize by sending GO command to motor.
Planarize.
Get encoder feedback.
Wait until move is complete. Send KILL command to motor.
Wait for operator to complete task and confirm.
Record final position of kinematic modules.
Check Needle Positions.
NO
replanarize.
Needles Define Horizontal Plane.
YES
Done.

E.3 The Beta Prototype

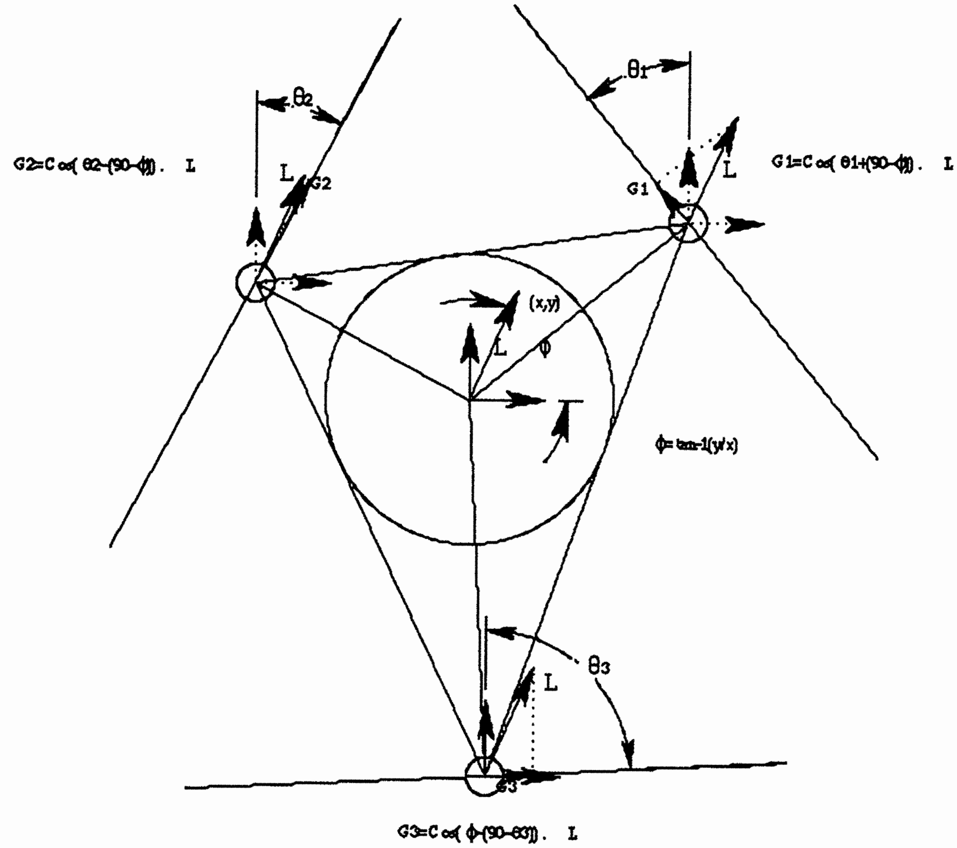


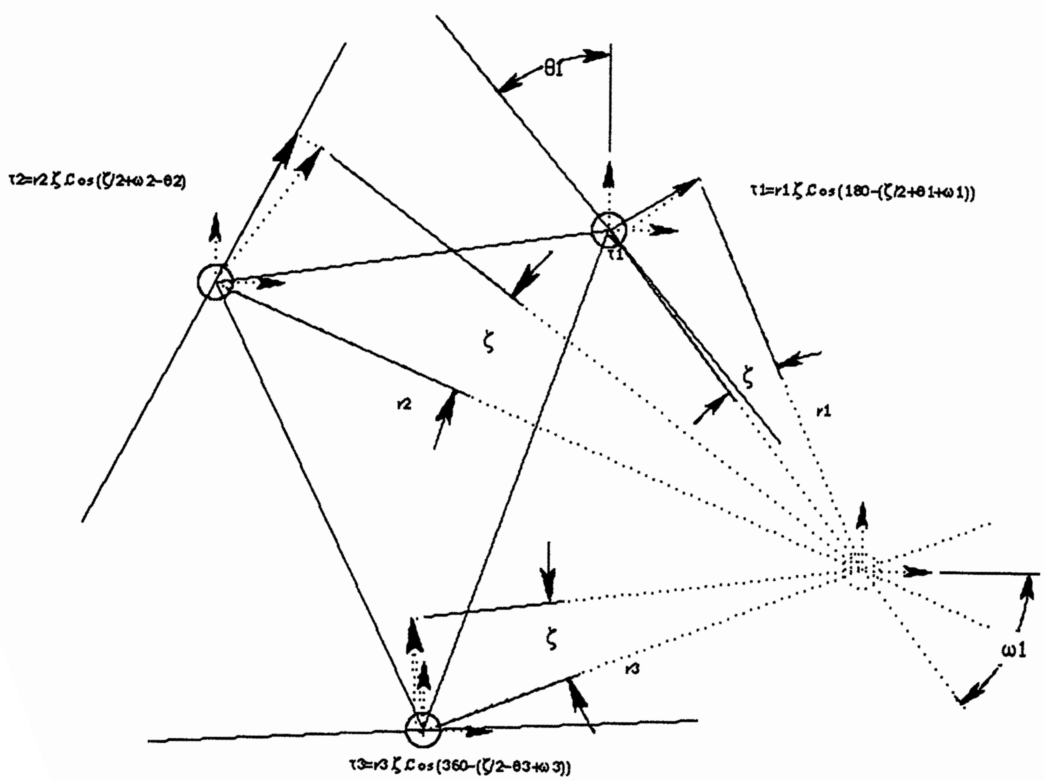


As the alpha prototypes were being tested and evaluated, Teradyne engineers continued work on the design and development of the beta prototype. The final design of the kinematic module would be frozen after the evaluation of this prototype. The beta module uses a very similar latch/preload mechanism as the alpha module. The worm gear assembly used to achieve preload in the alpha version is replaced with a simplified spur gear arrangement. In addition, the rolling element linear motion bearing is replaced by a dovetail bearing which provides the best combination of cost and performance. The z-height adjustment is performed manually by adjusting a wedge assembly located at the top of the module.

The beta prototype was an improvement over its predecessor in the following areas:

• Lower cost.
• Less assembly time.
• Hardened stainless steel ball and groove to avoid fretting.
• More ergonomic manual z-height adjustment.
• New V-groove design, which eliminates any pogo pin scrub by constraining the ball in the x,y directions.
• A sensor indicating whether the ball and the groove are latched or unlatched.
• Use of Eddie current sensors instead of mechanical microswitches which, break very easily.
• New design provides ample space for implementation of an autoplanarization mechanism.
• Adjustable V-groove in the x-y plane allows for the precise alignment of pogo pins with the DIB bond pads. The adjustment mechanism allows the operator to move the V-groove perpendicular to the direction of the groove. Since the balls can slide in the grooves, the testhead can be translated and rotated as necessary for proper alignment of the pogo pins with the bond pads. The following schematics demonstrate the effective translation and rotation which result by adjusting the V-grooves. L is the amount of desired translation and ζ is the desired angle of rotation. The angle between the y-axis and the adjustment axis (direction perpendicular to the V-groove) is denoted by θ. The grooves must be adjusted by an amount τ+G to obtain proper alignment.


θ2
θ1
G2=Cos(θ2-(90-ϕ)) . L
L
G2
G1
L
G1=Cos(θ1+(90-ϕ)) . L
(x,y)
L
ϕ
ϕ= tan-1(y/x)
θ3
L
G3
G3=Cos(ϕ-(90-θ3)) . L


θ1
τ2=r2 ζ Cos(ζ/2+ω2-θ2)
τ1=r1 ζ Cos(180-(ζ/2+θ1+ω1))
τ1
ζ
ζ
r2
r1
ζ
r3
ω1
τ3=r3 ζ Cos(360-(ζ/2-θ3+ω3))

Uses of the Engineering Case Study

Chapter 5

5.1 Alternative Uses of the Engineering Case Study

Engineering Case Studies can be used in numerous ways. The alternatives can be grouped in three different categories:

1. Use as a basis for Master's programs.
2. Use in the classroom.
3. Use in industry and continuing education.

Sections 5.1.1, 5.1.2, and 5.1.3 will discuss each such category. Section 5.2 describes how the Teradyne Case Study was used in the classroom and at Teradyne, and how it will be used in the future.

5.1.1 Use of the Engineering Case Study as a Basis for Master's Programs

Most educational institutions require graduate students to conduct research in laboratories located on their campuses. The research completed in these laboratories often has immense scientific significance and could be valuable to industry. However, the industry which could benefit from the research rarely has access to it and might find it difficult to apply the theory to their specific needs. Furthermore, engineers enrolled in these programs often are isolated from the real world and do not face the real-life issues encountered by their fellow engineers in industry.

The proposed case-study-based Master's program seeks to resolve these problems. The traditional Master's program in Engineering can be significantly improved if the graduate student's education is based on writing an Engineering Case Study as opposed to the traditional Master's thesis. As discussed in Chapter 3, such a program would allow the student to get involved directly with industry from the outset. It would allow graduate students to conduct valuable research and get involved in real-life engineering activities at an industrial sponsor's facilities. In addition, in order to successfully write the Engineering Case Study, the proposed program would require students to: (i) assemble all the information relevant to the project upon which the case is based; (ii) weigh and sort pertinent facts; (iii) understand the technical and business trade-offs of a project; and (iv) establish the basis upon which the industrial sponsor could make engineering and marketing decisions. Thus, the proposed program would benefit both the student and the industrial sponsor.

5.1.2 Use of the Engineering Case Study in the Classroom

It often is difficult to make engineers aware of the issues that they will face in the real world. Engineering Case Studies can be used to introduce engineers to the intricacies of real-life engineering projects by exploring the trade-offs between technical and business issues. They can be used in a variety of ways in classrooms: as reading assignments, as illustration of theory, as background for specific problems, as material for problem definition, as subjects for class discussion, and as examination problems.

For example, the Teradyne Case Study could be rewritten for use in a Manufacturing class exploring issues such as design for manufacturing and design for assembly of the kinematic module. Alternatively, the case could be used as the background for specific design problems. Students would have the opportunity to apply their engineering design skills in a real-world setting. If the Teradyne Case Study had been used as such, the students might have been asked to design a kinematic coupling system which would address Teradyne's interfacing problems. The level of detail would be left to the discretion of the professor. It is this type of connection between theory and real-life application which renders problems more interesting to engineering students.

5.1.3 Uses of the Engineering Case Study in Industry and in Continuing Education

Engineering Case Studies can be used in the continuing education of professional engineers and managers. In many instances, professional engineers and managers can have a difficult time understanding the relevance of academic research to their field of work. Engineering Case Studies can be used as a bridge between theory and application. They are an effective means of connecting theory with reality, thereby keeping professionals updated with the latest technical and business issues and developments in their industries.

Engineering Case Studies also can be used within the corporations sponsoring the proposed Master's program, by focusing the engineering and marketing groups of the companies on the tasks at hand. Engineers will be made aware of the business issues related to new technology, while marketing group be better able to understand the underlying technology making the new product possible. Engineering Case Studies also can be used to prepare promotional literature to be distributed among potential customers.

5.2 Uses of The Teradyne Case Study

5.2.1 Use of the Teradyne Case Study in the Management for Engineers Class at MIT

The Teradyne Case Study was presented in Alex d'Arbeloff's Management for Engineers class at MIT in the Spring of 1995. The purpose of the case study was to give students an opportunity to learn more about the dynamics of a real-life engineering project and to give them a better understand the trade-offs between business and technical issues. Their assignment was to present a sales plan for the new product developed at Teradyne.

The case was handed out to the students two weeks prior to the date upon which they would make the presentations of their assignments. This gave them ample time to read the case study. The class period prior to the final presentations was devoted to a Question and Answer session. In order to further enhance the students' understanding and involvement, several key members of the product development team of Teradyne were invited to attend this session. Among the attendees were the President and CEO of the company (who was, in this case, also the Professor presenting the case), the mechanical engineer leading the product development team, two product integration managers responsible for selling the new product, and the Graduate Student, who now was a member of the product development team at Teradyne. In addition, the students had the opportunity to contact the product development team members via e-mail during the week prior to the final presentations.

In general, students should take advantage of this session and other opportunities to better understand the technical and business issues faced by product development teams. In some cases, the technology described in the case study might be complex and difficult to visualize without physical models. An informational session as discussed above is an opportunity to present the students with prototypes or mock-ups of the technology being developed at the industrial sponsor's facilities. For purposes of the Teradyne Case Study, the class was presented with models demonstrating key concepts. Students also were presented with informational and promotional literature describing Teradyne's products.

The following week, the students' sales plans were presented and discussed in the class. As part of the class discussion, the Graduate Student gave a presentation which summarized the business and technical issues and proposed a sales strategy for Teradyne. Presentations by individuals involved with the industrial sponsor can be used as a starting point for class discussion which can provide the industrial sponsor with a fresh and objective outlook on the project.

5.2.2 Use of the Teradyne Case Study within Teradyne, Inc.

The Teradyne Case Study was used within the company in three ways:

- The Case was distributed among incoming engineers and managers as a means of updating them on the status of the project. The Case made the engineers fully aware of the technical and business challenges faced by the product development team.

- The Case was distributed among the Industrial/Consumer Division managers and product integration managers. The Case served as an update for those managers, who were involved with several other projects. In addition, it served as a means of conveying to the engineering and marketing groups any concerns and unresolved issues that they should address to ensure the success of the product in the marketplace.

- The Case was utilized by the Marketing Communication Group in order to prepare informational and promotional literature for potential consumers.

Conclusion

Chapter 6

This thesis proposed a new form of graduate study, in which a graduate student works with an industrial sponsor to draft an Engineering Case Study. Unlike the traditional business case study, the Engineering Case Study focuses on technological issues and explores the trade-offs between business and technical issues more comprehensively.

The advantages of the Engineering Case method are two-fold. First, the method itself allows the graduate student to integrate classroom and real life experience, and to get involved with a specific industry. The industrial sponsor benefits from the graduate student's involvement in the development of future technologies. Second, the Engineering Case Study which emerges from the process is also advantageous to both future education and to industry. The case can be used in engineering classes in much the same manner as traditional cases are used, while the industrial sponsor can use the Engineering Case Study in the continuing education of its employees.

An example of the proposed case-study-based Master's program was presented in the form of an Engineering Case Study completed at Teradyne, Inc., a semiconductor test equipment manufacturer. Preparation of the case benefited the graduate student, who gained real-life engineering experience. Furthermore, the Teradyne Case Study was found to be an effective means of conveying the project's critical issues to Teradyne's product development team. The case also was used within Teradyne to update managers and incoming engineers as to the status of the project.

Improvements to the process of creating an Engineering Case Study were outlined, as a guideline for future case-study-based Master of Science in Engineering programs. The process could have been improved by increasing the involvement of a faculty adviser, by establishing up-front how the graduate student would receive funding, and by increasing the time-frame for completion of the Engineering Case Study.